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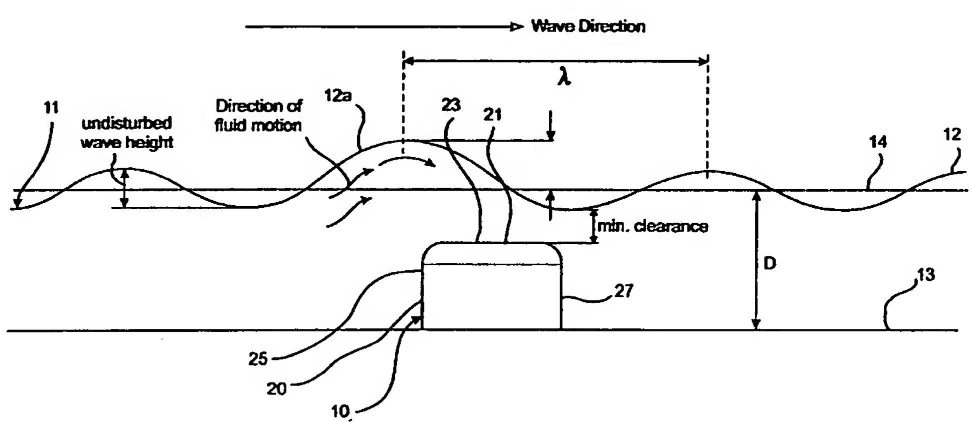

(57) Abstract: A method and device (10) for extracting useful energy from wave motion (12) in a body of water (11). The method involves providing the energy extraction device (10) having an energy collection surface (23) responsive to variations in hydrostatic pressure generated by wave motion; and positioning the energy extraction device in the body of water at a location where the body of water is at a depth D and a wave length λ. The ratio of water depth to wave length (D/λ) is in a range of about 0.1 to 0.5. Useful energy is delivered by the energy extraction device (10). With the ratio of water depth to wave length (D/λ) within the range prescribed above, the water may be considered to be in a regime intermediate between a deep water regime and a shallow water regime for the prescribed wave length. The energy extraction device (10) has a rigid surface (25) extending downwardly from the energy collection surface (23) for intercepting water disturbances generated by the wave motion (12) and deflecting the water disturbances to the region above the energy collection surface (23).

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"Wave Power Generator"

Field of the Invention

The present invention relates to extraction of energy from wave motion.

Background Art

The extraction of energy from periodic motions in bodies of water is a well-studied problem and various energy extraction devices have been proposed for such a purpose. One class of energy extraction devices that are disposed to intersect disturbances predominately at the surface of a body of water may be exposed to potentially damaging conditions, for example, in storms where the breaking of waves over a device can cause severe loadings on equipment and moorings. Survivability may be catered for under such conditions in the design of an energy extraction device, but it will incur extra production costs for heavier component ratings and will necessitate that the device has to shut down in large amplitude motions of the body of water. This limits the dynamic range over which such a device can operate.

It has long been recognised that survivability of an energy extraction device is enhanced if it is submerged so that no part of the device is exposed during even the most vigorous disturbance. In the ocean, for example, this means the uppermost surface of the device must lie below the wave trough of the largest waves experienced during the most adverse storm conditions.

Survivability is one reason there are a great many devices of a further class that have been conceived to lie on the bottom of a body of water. Cost is another reason. Devices can be emplaced on the seabed in shallow waters using barges and dredging equipment normally employed for cable laying or similar undersea activities. US 5,955,790 (North) discloses such a method of emplacement of small pressure devices. Devices of this class respond primarily to the dynamic pressure head, and less (or not at all) to the velocity distribution of the body of water.

A number of similar devices exist within this class. US 3,353,787 (Sumo) discloses a device comprising an array of parallel, flexible, fluid-filled tubes disposed on the seabed in shallow waters. Waves act to deform the upper surfaces of the tubes causing a pumping of the fluid in a closed system. Pressure accumulators and tidal accumulators are provided onshore. A similar device is disclosed by Graff US 4,001,597 (Graff) wherein an array of fluid pumps is disposed on the seabed. Each pump consists of a chamber with a piston that is driven by a pressure plate in response to vertical pressure fluctuations. Fluid is reticulated to a shore-based turbine and generator via a common high-pressure manifold.

Within the this class of devices is a sub group having energy conversion means located within the seabed device as opposed to onshore. US 4,630,440 (Meyerand) discloses a flexible air-filled bag located within a structure emplaced on the seabed. The change in bag volume in response to pressure variations forces seawater to pass through a turbine located within the structure. The turbine is connected to a generator to produce electricity. US 4,145,882 (Thorsheim) discloses a flexible chamber filled with fluid. The fluid is forced to move past a nozzle in response to the deformation of the chamber with wave motion. Fluid is passed though a turbine located within the nozzle and returned to the inlet in a closed cycle pumping system. The turbine is coupled to a generator for the production of electricity.

US 3,989,951 (Lesster) discloses a device located on the seabed and comprised of a series of three side-by-side chambers with flexible diaphragm coverings. The chambers are arranged parallel to the oncoming waves and are spatially disposed so that adjacent chambers pump fluid in anti phase from adjacent half cycles of the wave disturbance. The fluid flow is controlled by valves and feeds a common manifold in a closed cycle system with a turbine.

The disadvantage of devices located on the seabed is that they can only intersect a limited portion of the energy available in a vertical water column; namely, that portion at the bottom of the body of water. Analysis of the propagation of waves within a body of water shows that the energy field falls off rapidly with depth, with

a scale length equal to the ratio of water depth to wavelength. In deep water (that is, in water with a depth-to- wavelength ratio greater than or equal to ½) the falloff of energy with depth is exponential. Energy extraction devices on the bottom in deep waters therefore receive very little energy.

For shallow water (that is, water where the depth-to-wavelength ratio is less than 1/20) the fall-off in energy with depth is much more gradual and there is more energy available at the bottom, though this is still only a portion of the total available energy. Devices coupling to the dynamical pressure variation will receive more energy than those in deeper water for the same surface wave disturbance, but there is also the added factor in shallow water of the velocity distribution. Wave disturbances in shallow water have significant horizontal velocity fields across the whole depth, and devices emplaced on the seabed that can only respond to vertical disturbances are not intercepting all the available energy. Some devices, such as that of US 4,145,882 (Thorsheim), are able to respond to both horizontal and vertical forces at the seabed.

Shallow water, as herein defined, poses another difficulty for seabed energy extraction devices. The presence of a significant horizontal velocity field can lead to appreciable wave energy losses through frictional agitation of the seabed. This is particularly true if the seabed is composed of loose sand. A consequence of this is the reduction in energy density at the seabed.

The balance between deepwater operation, where the energy density is intrinsically low, and shallow water operation, where frictional losses are present, leads to a broad optimum depth where neither of these effects is dominant and the available energy for a seabed device is a maximum. Similar optimum depth constraints also apply to the former class of devices that are disposed at or near the surface.

The problem with both surface and seabed energy extraction devices is the limited vertical extent of their operation leading to energy capture of only a portion of the available wave energy. US 6,291,904 (Carroll) addresses this in respect of near surface devices. Carroll discloses a wave energy converter using pressure

differences, which can couple to the majority of the energy in the water column using a long tubular collector. The disadvantages of such a system are the unwieldiness of the device; the length of the cylinder is equal to half the water depth, and it must be kept anchored with the top just below the water surface.

It is against this background, and the problems and deficiencies associated therewith, that the present invention has been developed.

Disclosure of the Invention

According to a first aspect of the invention there is provided a method of extracting useful energy from wave motion in a body of water, comprising: providing an energy extraction device having an energy collection surface responsive to variations in hydrostatic pressure generated by wave motion; positioning the energy extraction device in the body of water at a location where the body of water is at a depth D and a wave length λ, wherein the ratio of water depth to wave length (D/λ) is in a range of about 0.1 to 0.5; and extracting useful energy delivered by the energy extraction device.

With the ratio of water depth to wave length (D/λ) within the range prescribed above, the water may be considered to be in a regime intermediate between a deep water regime and a shallow water regime for the prescribed wave length.

Preferably, the method further comprises providing the energy extraction device with a rigid surface in opposing relation to the oncoming wave distribution in the body of water.

Preferably, the energy collection surface has an extent in the direction of wave motion and the rigid surface extends downwardly from adjacent the energy collection surface.

According to a second aspect of the invention there is provided a system for deriving useful work from wave motion, the system comprising a body of water subject to wave motion on the surface thereof, an energy extraction device

submerged in the body of water, the energy extraction device having an energy collection surface responsive to variations of hydrostatic pressure arising from the wave motion, the energy extraction device being submerged in the body of water at a location where the water is of a depth D and of a wave length λ, with the ratio of water depth to wave length (D/λ) being in the range of about 0.1 to 0.5.

According to a third aspect of the invention there is provided a system for deriving useful work from wave motion, the system comprising a body of water subject to wave motion on the surface thereof, an energy extraction device submerged in the body of water, the energy extraction device comprising an energy collection surface responsive to variations of hydrostatic pressure arising from wave motion above the energy collection surface, and a rigid surface extending downwardly from the energy collection surface for intercepting water disturbances generated by the wave motion and deflecting the water disturbances to the region above the energy collection surface.

Preferably, the energy collection surface has an extent in the direction of wave motion and the rigid surface extends downwardly from adjacent the energy collection surface.

According to a fourth aspect of the invention there is provided an energy extraction device for extracting energy from wave motion in a body of water, the energy extraction device comprising a body having an energy collection surface responsive to variations in hydrostatic pressure arising from wave motion above the energy collection surface, and a rigid surface extending downwardly from the energy collection surface for intercepting water disturbances generated by the wave motion and deflecting the water disturbances to the region above the energy collection surface.

Preferably, the body has an upper surface in which the energy collection surface is incorporated.

Preferably, the upper surface of the body has a rigid section adjacent to the energy collection surface, the rigid section being disposed to the side of the energy collection surface opposite to the oncoming wave disturbances.

Preferably, the energy collection surface comprises a deflectable diaphragm. Typically the diaphragm is flexible to provide the prescribed deflectable characteristic. The diaphragm may comprise a membrane of any appropriate material such as rubber or a synthetic hydrocarbon polymer such as polyurethane. It should, however, be appreciated that the diaphragm may be of any other appropriate construction, such as for example a flexible wall constructed of sealingly interconnected articulated elements, or a thin inner membrane bonded to an array of articulated elements, the latter providing mechanical strength.

The body may define a pumping chamber containing a working fluid, a wall of the pumping chamber being defined by a diaphragm whereby deflection of the diaphragm in response to wave motion acts on working fluid contained in the pumping chamber to cause motion thereof.

Typically, the working fluid comprises air, although it may be any other appropriate gas or gaseous mixture.

The energy conversion device may further comprise conversion means responsive to motion of the working fluid for converting kinetic energy in the moving working fluid to an energy form that can be delivered as useful work.

Preferably, the conversion means comprises a fluid motor (such as a turbine) for converting the motion of the working fluid to rotary motion from which mechanical power can be extracted as shaft power. The mechanical power can be used in any suitable way such as, for example, to drive an electrodynamic machine for generating electricity.

The body may incorporate two zones and a flow path between the two zones along which the working fluid can move between the two zones, the fluid motor

being associated with the flow path. Typically, the zones comprise chambers in the body.

The pumping chamber and the fluid machine are preferably incorporated in a circuit around which the working fluid moves.

The flow direction of working fluid around the circuit may be controlled in any appropriate way, typically by one-way valves. For example, one-way valves may be provided to control entry of working fluid into, and discharge of working fluid from, the pumping chamber.

In one arrangement, the circuit around which the working fluid moves may further include an accumulator chamber and a transitional chamber, the arrangement being that the working fluid is delivered from the pumping chamber into the accumulator chamber upon inward deflection of the diaphragm to preform discharge stroke of the pumping chamber, the working fluid accumulating in the accumulator chamber until it attains a prescribed pressure whereupon it flows through the fluid motor and into the transitional chamber, the working fluid returning from the transitional chamber to the pumping chamber upon outward deflection of the diaphragm to perform an intake stroke of the pumping chamber.

In another arrangement, the circuit around which the working fluid moves may include a further chamber, the pumping chamber and the further chamber being connected for fluid communication therebetween by means of a delivery path and a return path, the fluid motor being associated with the delivery path, the arrangement being that working fluid is delivered from the pumping chamber to the further chamber to flow through the fluid motor upon inward deflection of the diaphragm to perform a discharge stroke of the pumping chamber, and working fluid returning from the further chamber to the pumping chamber upon outward deflection of the diaphragm to perform an intake stroke of the pumping chamber.

Preferably, the further chamber is of constant volume in the sense that it is not affected by variations in hydrostatic pressure arising from the work motion.

Typically, the further chamber is disposed beneath the rigid section of the upper surface of the body.

In still another arrangement, the energy extraction device comprises two diaphragms in spaced apart relation along the direction of wave motion.

The device may comprise a multitude of pumping chambers operatively connected one to another in series such that the pressure of the working fluid is progressively increased as it moves from one pumping chamber to the next pumping chamber in the series. Typically, one-way valves would control the flow direction of working fluid from one pumping chamber to the next pumping chamber.

Brief Description of the Drawings

The invention will be better understood by reference to the following description of what several specific embodiments thereof as shown in the accompanying drawings in which;

Figure 1 is a schematic elevational view illustrating wave disturbances associated with an energy extraction device according to a first embodiment;

Figure 2 is a perspective view of the device according to the first embodiment;

Figure 3 is a schematic elevational view illustrating the device according to the first embodiment installed in position on a seabed;

Figure 4 is a schematic sectional elevational view of the device according to the first embodiment;

Figures 5 to 8 are schematic elevational views illustrating the device according to the first embodiment in operation in response to wave action;

Figure 9 is a schematic side view of an energy extraction device according to a second embodiment;

Figure 10 is a plan view of the device shown in Figure 9;

Figure 11 is a schematic side view illustrating an energy extracting device according to a third embodiment installed on a seabed;

Figure 12 is a plan view of the device according to the third embodiment;

Figure 13 is a schematic sectional view of the device according to the third embodiment;

Figures 14 to 17 are various schematic elevational views illustrating the device according to the third embodiment in operation in response to wave action;

Figure 18 is a schematic sectional view illustrating an energy extraction device according to a fourth embodiment installed on a seabed;

Figure 19 is a plan view of the energy extract device according to the fourth embodiment;

Figure 20 is a schematic view illustrating the relationship between the profile of the diaphragms and the wave activity.

Figures 21 to 28 are various views illustrating the device according to the fourth embodiment in operation;

Figure 29 is a schematic side view of an energy extraction device according to a fifth embodiment;

Figure 30 is a view similar to Figure 29 with the exception that the device is shown in operation in response to wave action;

Figure 31 is a schematic perspective view of an energy extraction device according to the sixth embodiment;

Figure 32 is a view similar to Figure 31 with the exception that the device is shown in operation in response to wave action;

Figure 33 is a schematic perspective view of an energy extraction device according to a seventh embodiment; and

Figure 34 is a view similar to Figure 33 with the exception that the device is shown in operation in response to wave action.

Best Mode(s) for Carrying Out the Invention

Referring first to Figure 1 of the drawings, there is shown an energy extraction device 10 according to a first embodiment submerged in a body of water 11 which is typically the sea. The device 10 is installed on the seabed 13 at a water depth D. At the location of the installation, the body of water 11 has wave activity of wavelength λ. The wave activity 12 is referenced with respect to undisturbed sea level 14.

The overall height of the device 10 and the water depth D are so selected that the device remains below the level of wave troughs up to reasonable amplitude of waves such that the device is submerged under normal operating conditions.

The device 10 comprises a body 20 having an upper end 21 incorporating an energy collection surface 23 as will be explained in more detail later. The body 20 further comprises a rigid deflecting surface 25 extending downwardly from the energy collection surface 23 for intercepting water disturbances generated by the wave motion and deflecting the water disturbances to the region above the energy collection surface 23.

In this embodiment, the rigid deflecting surface 25 is defined by an upright peripheral wall 27 of the body 20.

The rigid deflecting surface 25 may be considered to be an upward deflector of water approaching the surface to cause upward welling of the water and thus peaking of the wave immediately above the deflecting surface, as illustrated in Figure 1. This effect arises because of the sudden change in water depth arising from the presence of the body 20 presenting the upright rigid deflecting surface 25 to the oncoming water. The effect is somewhat similar to shoaling which occurs with wave activity over a submerged reef or raised portion of a seabed.

It is desirable to upwardly deflect the maximum quantity of water from a wave disturbance and to produce the maximum shoaling effect. This leads to a significant increase in wave height above the energy collection surface 23 and gives rise to an enhanced energy pulse as the energy collection surface responds to the weight of this body of water.

The ratio of water depth to wavelength (D/λ) is preferably less than 0.5, and preferably greater than 0.1, so that the water may be considered to be in a regime intermediate between the deepwater regime and the shallow water regime for this wavelength. The field of wave energy within a vertical water column can then be considered to be falling off gradually with increasing depth from the surface. It should be understood that under these conditions there is a region below the water line extending to a depth D_x where x % of the total energy of the travelling wave disturbance resides. The parameters (D_x,x) are determined primarily by the ratio D/λin the case of linear wave theory.

The shoaling effect can be optimised by judicious selection of the device height and distance given the depth of water and wavelength of the wave disturbances. The optimisation proceeds as follows. For a given depth D and wavelength λ, the ratio D/λ is determined and then linear wave theory is used to determine the parameter set (D_x,x) as explained above. A value of x, say 80%, is selected and the value D_{80} is determined, D_{80} being the depth below surface within which 80 percent of the wave energy is contained. The height of the device is adjusted so that the depth from the surface D_x reaches as far as possible down the deflecting surface 25 of the device consistent with the constraint that the device must be

submerged beneath the wave trough line. It may be necessary to iterate the process and reselect a different value for the depth that is, relocate the position of the device in order to obtain a satisfactory solution.

By way of example, a suitable set of parameters is as follows: (i) a water depth of 20 metres; (ii) a wavelength of wave 89 meters for an 8 second period wave; (iii) side wall height of 15 metres with a further one metre to the top of the top surface; (iv) a clearance of 4 metres between the top and the undisturbed water level; and (v) a minimum clearance of 1 metre of water between the top surface and a wave trough for a maximum 6 metre swell (i.e. 3 metres peaks and 3 metre troughs).

The construction of the device 10 according to the first embodiment is best seen in Figures 4 to 8 of the accompanying drawings. The body 20 is of generally cylindrical construction, comprising a base 31 adapted to rest on the seabed 13, with the peripheral wall 27 extending upwardly from the perimeter of the base 31. A diaphragm 35 is provided on the upper end of the peripheral wall 27. The diaphragm 35 defines the energy collection surface 23 as well as the upper end 21 of the body 20. The diaphragm 35 has an extent L in the direction of wave motion. The extent L of the diaphragm 35 is of a dimension no more than one half of the wave length of the longest period wave to which the device 10 is likely to be exposed.

Various chambers are defined within the body 20, including a pumping chamber 41, an accumulator chamber 42 and a transitional chamber 32. As can be seen from the drawings, the pumping chamber 41 is uppermost and disposed immediately beneath the diaphragm 35, the accumulator chamber 42 is lowermost, and the transitional chamber 43 is between the pumping chamber and the accumulator chamber.

The chambers 41, 42 and 43 contain a working fluid which in this embodiment is air.

The pumping chamber 41 communications with the accumulator chamber 42 by way of a fluid transfer passage 45 extending therebetween. The fluid transfer

passage 45 comprises a duct 47 having one end thereof communicating with the pumping chamber 41 and the other end thereof communicating with the accumulator chamber 42.

A control valve 51 is provided for controlling flow of working fluid from the pumping chamber 41 to the accumulator chamber 42. The control valve 51 is associated with the duct 47 and is operable in response to fluid pressure in the pumping chamber 41 attaining a prescribed level whereupon the control valve 51 opens to allow working fluid to flow from the pumping chamber 33 to the accumulator chamber 37. The control valve 51 also serves to prevent reverse flow of working fluid from the accumulator chamber 42 to the pumping chamber 41. This can be achieved by the control valve 51 being arranged to close when fluid pressure in the pumping chamber 41 drops to, or at least falls to a level approaching, the pressure in the accumulator chamber 42.

The device 10 also incorporates a fluid motor 53 in the form of a turbine driving a load 54 such as an electrodynamic machine for generating electricity.

The turbine 53 has turbine blades 55 located in a flow path 57 between the accumulator chamber 42 and the transitional chamber 43. The flow path 57 comprises a port in a wall 59 between the two chambers. When the fluid pressure in the accumulator chamber 42 is sufficient, the working fluid under pressure in the accumulator chamber 42 passes through the turbine blades 55 into the transitional chamber 43, so imparting rotational energy to the turbine blades 55.

A fluid return path 61 is provided between the transitional chamber 43 and the pumping chamber 41. The fluid return path 61 comprises a return port 63 provided in a wall 64 between the two chambers. A return control valve 65 is associated with the return port 63 to allow fluid flow from the transitional chamber 43 to the pumping chamber 41 while preventing return flow when the pumping chamber is under compression.

The end of the duct 47 opening onto the pumping chamber 41 is spaced further from the deflecting surface 25 than is the fluid return path 61, as can be seen in

the drawings. The purpose of this spatial relationship between the fluid return path 61 and the duct 47 will become apparent later.

The device 10 is provided with a compressed air supply 67 for initially charging the chambers 41, 42 and 43 with compressed air, as well as providing any replenishment air which may be necessary. Additionally, the compressed air supply 67 can be arranged to deliver supplementary air to the pumping chamber 41 for further inflating the diaphragm 35 as may be necessary. In this regard, it is possible to vary the depth of the diaphragm 35 below the water surface by inflating or deflating the diaphragm 35 through appropriate variations of the static air pressure within the pumping chamber 41. It is desirable to maintain the apparatus at a particular depth below the water surface in order to optimise extraction of energy from the waves. By appropriate inflation or deflation of the diaphragm 35, it is possible to shift the height of the diaphragm 35 relative to the seabed 13 (and hence its depth below the water surface) to compensate for fluctuations in sea conditions such as the state of the waves and tidal variations. The chambers 41, 42 and 43 are charged with air by way of air line 68 communicating with the chamber 41.

Operation of the device according to the first embodiment will now be described with reference to Figures 5 to 8 of the accompanying drawings. As can be seen from the drawings, the device 10 is installed on the seabed 13 at a water depth within the parameters discussed earlier, where it remains submerged throughout its entire operation in normal circumstances. This is advantageous as it minimises exposure of the apparatus to the effects of adverse sea conditions.

An approaching wave (depicted by line 12), as shown in Figure 6, is deflected by the presence of the deflecting surface 25 to provide an enhanced wave condition 12a which increases the mass of water above the diaphragm 35. The wave action, together with the increased mass of the water in the wave above the diaphragm 35, causes the diaphragm 35 to progressively deflect, as shown in Figures 6 and 7. The deflection of the diaphragm 35 in response to the wave decreases the volume of the pumping chamber 41 and hence increases the pressure of the working fluid. When the working fluid attains a prescribed

pressure, the control valve 51 opens to allow the working fluid to pass from the pumping chamber 41 into the accumulator chamber 42. The increase in pressure in the accumulator chamber 42 reaches a level at which it can drive the turbine 53 and pass into the transitional chamber 43. As the working fluid acts on the turbine 53 in moving from the accumulator chamber 42 to the transitional chamber 43, it imparts rotation to the turbine blades 55 and thus rotational energy to the shaft on which the turbine blades are carried. The spent working fluid in the transitional chamber 43 returns into the pumping chamber 41 via the return port 63 upon expansion of the pumping chamber 41 during the second period of the wave, as shown in Figure 8. The process continues with ongoing wave action causing the working fluid to move through a circuit from the pumping chamber 41 to the accumulator chamber 42, from where it acts on the turbine 53 in passing into the transitional chamber 43, and finally returning the pumping chamber 41. The movement of the working fluid is converted to rotational energy at the turbine 53 for driving the load 54.

The duct 47 is spaced away from the deflecting surface 25 so as to avoid being blocked or otherwise obstructed by the deflecting diaphragm 35.

The diaphragm 35 is deflected downwardly to cause a volume reduction of the pumping chamber 41 under the influence of the wave action. The diaphragm 35 performs a return stroke by virtue of its inherent resiliency, as well as suction effects by the wave and the return of working fluid into the pumping chamber 43. There may, however, be circumstances where it would be desirable to provide a supplementary mechanism to assist the diaphragm 41 to perform its return stroke. This can be done in any appropriate way. One such way would involve the utilisation of one or more vanes or like structures on the outer face of the diaphragm 35 to utilise wave energy to draw the diaphragm along its return stroke. Another way may involve the incorporation of buoyancy into the diaphragm. A still further way may involve the introduction of a charge of air into the pumping chamber 41 when it is at its minimum volume condition so as to provide an increase in pressure for initiating the return stroke.

The volume of the transitional chamber 43 is much larger than the volume of the accumulator chamber 42 for the purposes of establishing pressure differentials therebetween to permit working fluid to flow from the accumulator chamber 42 into the transitional chamber 43 and thereby drive the turbine 53.

The body 20 incorporates a provision for accessing the interior thereof for the purposes of maintenance and repair. In this regard, an exterior access door 71 is provided in the peripheral wall 27. The door 71 opens onto an airlock compartment 73 from which access to the interior of the body can be obtained by way of interior access door 75.

In the first embodiment, the body 20 was generally cylindrical. Such a configuration is advantageous in that it is omni-directional in the sense that it can respond to wave action regardless of the direction from which waves approach the device. Because of the circular configuration of the peripheral wall 27, the deflecting surface 25 defined by the peripheral wall can vary according to the direction of approaching waves.

The embodiment shown in Figures 9 and 10 is not omni-directional as was the case with the first embodiment but rather is uni-directional. In this regard, the deflecting surface 25 is planer as opposed to cylindrical and thus the entire extent of the deflecting surface extends transversely of approaching wave motion, which may be advantageous in certain applications. In this embodiment, the body 20 is generally rectangular, such that one side wall thereof defines the deflecting surface.

While the first and second embodiments each utilise a body 20 having a peripheral wall 27 which extends downwardly to the seabed 13, it should be understood that this need not always be the case. In other arrangements, the body 20 could be supported in an elevated condition above the seabed, such as on legs. It is important that the deflecting surface 25 extend downwardly from the diaphragm 35, to an extent sufficient to cause the required deflection of water, although it is not essential that it extend entirely to the seabed.

Referring now to Figures 11 to 17, there is shown a device 80 according to a third embodiment. The device 80 comprises a body 81 having a rigid structure 83 emplaced on the seabed 13. The rigid structure 83 is generally rectangular in section view and plan view, and has a bottom wall 85, a top wall 87, two side walls 88 and two end walls 89. One of the end walls 89 defines a deflecting surface 90 which is presented to oncoming wave disturbances, as was the case with the earlier embodiments.

The body 81 incorporates an energy collection surface 95. The energy collection surface 95 comprises a diaphragm 97 sealingly fitted to the rigid structure 83 about an aperture 99 provided in the top wall 87 of the rigid structure 83. In this embodiment, the diaphragm 97 and the aperture 99 around which it is fitted are both generally rectangular. With this arrangement, the diaphragm 97 has an extent L in the wave direction. The extent L of the diaphragm 97 is of a dimension no more than one half of the wave length of the longest period wave to which the device 80 is likely to be exposed.

The aperture 99 is located in the top wall 87 at one end thereof adjacent the deflecting surface 90 and is thus disposed towards the direction of oncoming wave disturbances. The dimensions of the aperture 99 are such that it is approximately equally spaced from the end wall 89 defining the deflecting surface 90 and the two side walls 88, as best seen in Figure 12 of the drawings.

The body 81 defines an interior 100 which includes a first chamber 101, a second chamber 102 and a third chamber 103. The second and third chambers 102 and 103 are substantially different in volume from each other. Additionally, the first chamber is substantially smaller in volume than the third chamber 103, the reasons for which will become apparent later.

The first chamber 101 is defined in part by the diaphragm 97 and is thus of a volume which varies with deflection of the diaphragm 97.

A partition wall 105 is provided within the interior 100 of the body 81. The partition wall 105 separates the first and third chambers 101, 103, as shown in the

drawings. Additionally, the partition wall 105 cooperates with the top wall 87 of the body to define a flow path 107 extending between the first chamber 101 and the third chamber 103.

A nozzle structure 109 is accommodated within the flow path 107. The nozzle structure 109 comprises a converging inlet section 111, a diverging outlet section 113 and a throat section 115 disposed between the inlet and outlet sections. A fluid motor in the form of a turbine 117 is accommodated in the throat section 117. The turbine 117 is drivingly connected to a load 119 which in this embodiment is an electrodynamic machine such as a generator.

The ratio of the volume of the first chamber 101 to the volume of the third chamber 103 is small in order to minimise the pressure build-up in the chamber 103 thereby maximising the transfer of potential energy in the form of pressure to kinetic energy in the working fluid presented to the turbine 117.

A one-way control valve 121 is provided for controlling flow of working fluid from the first chamber 101 to the flow passage 107.

The second chamber 102 is defined between the control valve 121 and the turbine 117.

A flow path 123 is provided between the third volume 103 and the first volume 101. The flow path 123 is defined by a port 125 in the partition wall 105. A control valve 127 is associated with the flow path 123 to allow working fluid to flow from the third chamber 103 to the first chamber 101 while preventing return flow.

The control valves 121 and 127 comprise flap valves of known kind which open in response to pressure differences. Closure of such valves is accomplished by subsidence or reversal of the pressure difference, and may be assisted by gravity or an appropriate biasing system. In this embodiment, the control valve 121 comprises a single flap valve oriented vertically, and the control valve 127 comprises a multitude of flap valve elements positioned in parallel and oriented horizontally. The multitude of flap valve elements defining valve 127 are able to

allow passage of a large volume of working fluid from the third chamber 103 to the first chamber 101 with minimal pressure difference and fluid velocity. Conversely, the single flap defining the control valve 121 is sufficient to allow passage of fluid at somewhat higher velocity and pressures consistent with the flow conditions within the nozzle 109.

It is a feature of the embodiment that the nozzle structure 109 and the turbine 117 accommodated therein are disposed horizontally rather than vertically as was the case with the earlier embodiments. The horizontal orientation of the nozzle structure 109 allows it to be of a larger length than would be the case if it were disposed vertically. The nozzle structure 109 is of a length which allows a provision of the converging inlet section 111 on the upstream side of the turbine 117 and the diverging outlet section 113 on the downstream side of the turbine. Such nozzle geometry is favourable for the acceleration of working fluid towards the turbine 117 and for minimising losses associated with the acceleration of the working fluid.

Operation of the device 80 according to the third embodiment will now be described with reference to Figures 14 to 17.

Figure 14 shows the device 80 at rest, with the previous wave disturbance having fully receded and the diaphragm 97 fully inflated. The volume of fluid within the chambers 101, 102 and 103 is adjusted so that the diaphragm 97 is fully extended above the level of the top wall 87. The pressures in each chamber are approximately equal and there is no fluid flow through the turbine 117 and the nozzle 107. Both sets of one-way valves 121, 127 are closed.

Figure 15 shows the device 80 at a time shortly after that depicted in Figure 14. The next wave disturbance is approaching the diaphragm 97 and is the wave amplitude is consequently increasing. The diaphragm 97 meanwhile is experiencing a dynamic force from the approaching body of water and this causes the diaphragm to deflect downwards. Pressure within the first chamber 101 increases due to the reduction of volume and this causes the control valve 121 to

open. The control valve 127 remains closed. Working fluid begins to flow through the nozzle 107 past the turbine 117 causing it to turn.

With reference to Figure 16 there is seen the state of the device 80 at a time subsequent to the event depicted in Figure 15. The diaphragm 97 is maximally extended downwards and the maximum weight of water is disposed thereupon. Working fluid is continuing to flow through the nozzle structure 109 and turbine 117 but the maximum power stroke has already occurred. Pressures in the chambers 101, 102 and 103 are approaching a common value and the flow rate through the nozzle 107 is reducing. At some point soon thereafter, the flow stops and control valve 121 closes. The control valve 127 also closes momentarily.
With reference to figure 17 is seen the situation shortly after that depicted in figure 16. The wave disturbance is receding and the dynamic force on the diaphragm 97 is relaxed. The pressure in the first chamber 101 is now less than the chamber 103 causing the control valve 127 to open. The re-equalization of pressure assists the diaphragm 97 in reinflating ready to start the process anew. Shortly thereafter the pressures in the chambers 101, 102 and 103 approach a common value and the control valve 127 closes.

Referring now to Figures 18 to 25, there is shown a device 130 according to a fourth embodiment. As in all the previous embodiments, the device 130 comprises a body 134 emplaced on the seabed 13 to receive energy from wave disturbances. The height of the body 134 and the depth of water coverage dispose the device 130 to cause shoaling of the incident wave disturbances as in the previous embodiments.

The body 134 is of generally rectangular construction, comprising a bottom wall 136 and a peripheral wall 138 upstanding from the bottom wall. The peripheral wall 138 comprises two opposing side wall portions 140 and two opposing end wall portions 144. One side wall portion 140 defines a deflecting surface 150 presented to oncoming wave disturbances, as was the case with previous embodiments.

The body 134 defines a first outer chamber 131, a second outer chamber 132 and an inner chamber 133 disposed between the two outer chambers 131, 132. Neighbouring chambers are separated by common internal walls 135 extending upwardly from the bottom wall 123.

The longitudinal extent of the rectangular body 134, and also of each of the three chambers 131, 132 and 133, is parallel to wavefronts of oncoming wave disturbances approaching the deflecting surface 150.

The inner chamber 133 has a rigid top wall 137. The first outer chamber has a top wall defined by a first diaphragm 141 and the second outer chamber 132 has a top wall defined by a second diaphragm 142.

The inner chamber 133 accommodates a nozzle structure 145 having a converging inlet section 147, a diverging outlet section 148 and a throat section 149 therebetween. A turbine 151 is accommodated in the throat section 149. This arrangement is somewhat similar to the arrangement in the previous embodiment.

Working fluid passes between the two outer chambers 131, 132 in response to deflection of the respective diaphragms, 141, 142, as will be explained in more detail. The turbine 151 is a conventional uni-directional turbine and so a flow control system is require for controlling the flow direction of working fluid between the two chambers 141, 142 in relation to the turbine 151 such that the flow is in a common direction thereby to rotate the turbine in its working direction.

The control system comprises a rectifying valve system involving an inlet zone 153 adjacent the inlet section 141 of the nozzle structure 145 and an outlet zone 155 adjacent the outlet section 148 of the nozzle structure. The first outer chamber 131 communicates with the inlet zone 153 by way of one-way valve 161. Similarly, the second outer chamber 132 communications with the inlet zone 153 by way of a second one-way valve 162. The outlet zone 155 communicates with the first outer chamber 131 by way of a third one-way valve 163. Similarly, the

outlet zone 155 communicates with the second outer chamber 132 by way of a fourth one-way valve 164.

The one-way valve 161 and 162 act in opposition, as do the one-way valves 163 and 164.

The various valves are disposed obliquely at the zones 153, 155 adjacent entrance and exit of the nozzle structure 145 so as to effect alternately the direction of fluid into and out of the outer chambers 131, 132.

As mentioned above each of the one-way valves at the ends of the nozzle structure 145 operate in opposition to its adjacent partner. Consequently, valves 162 and 163 operate in unison but in the reverse of valves 161 and 164. This arrangement affords a means of continually exchanging working fluid between the outer working chambers 131, 132 via the nozzle structure 145 while maintaining a common direction of fluid flow through the turbine; in other words, there is rectification of the fluid flow.

As best seen from Figure 20, the two diaphragms 141, 142 have centres spaced approximately equal to one-half of the length of the predominant wave disturbances to which they are exposed. With this arrangement, the two outer chambers 131, 132 operate in a "push-pull" configuration, enabling energy extraction over the full cycle of a wave disturbance. This is best seen with reference to Figures 21 to 28 of the drawings.

Figures 21 and 22 illustrate the device 130 in the condition where the first diaphragm 141 has deflected downwardly into a maximally extended condition under the influence of the weight of water disposed thereon. During the downward deflection of the diaphragm 141 to that maximally extended condition, the volume of the first outer chamber 131 progressively decreased thereby causing working fluid contained therein to flow through the inner chamber 133, and the nozzle 145 and turbine 151 accommodated therein, into the second outer chamber 132. The one-way valve 161 and 164 opened to permit such fluid flow, while valves 162 and 163 remained closed. During that volume reduction of the

first chamber 131, working fluid is returning to the second chamber 132 causing upward deflection of the diaphragm 142.

Figures 23 and 24 show the device 120 at a time shortly after the state depicted in Figures 21 and 22. At this stage, the device is at rest with both diaphragms 141, 142 assuming similar positions, and the various one-way valves are closed.

Figures 25 and 26 illustrate the device 120 at a time shortly after the state depicted in Figures 23 and 24. At this stage, the second diaphragm 141 is maximally extended downwards and the maximum weight of water is disposed thereon. During deflection of the diaphragm to such a condition, the volume of the second outer chamber 132 progressively decreases thereby causing working fluid contained therein to flow towards the first chamber 131 via the inner chamber 133. Working fluid returning to the first outer chamber 131 causes upward deflection of first diaphragm 141.

Figures 27 and 28 show the device at a time shortly after the state depicted in Figures 25 and 26 and essentially repeat the state illustrated in Figures 21 and 22.

Referring now to Figures 29 and 30, there is shown a device 180 according to a fifth embodiment. The device 180 comprises a plurality of pumping chambers 181 connected in series, with each pumping chamber communicating with the next pumping chamber via a one-way valve 183 for permitting working fluid to flow through the series of working chambers from a low pressure end thereof to a high pressure end thereof while preventing flow in the reverse direction.

The spacing between successive pumping chambers 181 in the series is arranged in relation to the wave length of the waves such that one pumping chamber undergoes an expansion stroke while the next pumping chamber undergoes a compression stroke, and vice versa throughout the series of pumping chambers.

The pump chambers 181 are incorporated in a circuit 185 which includes a turbine 187.

Each chamber 181 has a rigid bottom wall 189 and a diaphragm 191 defining a flexible upper wall. The bottom walls 189 of the series of pumping chambers 181 may be formed as a common structure. Similarly, the flexible diaphragm 191 may be a common structure.

The circuit 185 includes an inlet 193 through which working fluid enters the series of working chambers 181 and an outlet 195 through which the working fluid leaves the series of working chambers at a significantly higher pressure.

In operation, working fluid enters the first working chamber 181 through inlet 193. Upon compression of the first working chamber, working fluid is pressurised and caused to flow into the next working chamber which at this stage is undergoing an expansion stroke. Subsequent compression of that second working chamber causes working fluid contained therein to be pressurised and delivered into the next working chamber which at this stage is undergoing an expansion stroke. The process continues, with working fluid in each working chamber 181 being delivered into the next working chamber at an increased pressure. The one-way valves 183 between working chambers prevent working fluid flow in the reverse direction. Ultimately, working fluid is delivered at high pressure to the outlet 195 from where it flows along the circuit 185 to the turbine 187. The working fluid acts on the turbine to cause rotation thereof for conversion of the energy in the working fluid to rotational energy. The spent working fluid then flows to the inlet 193 for the process to be repeated.

The flow circuit 185 may incorporate hinged joints 186 to accommodate relative movement between the pumping chambers 181 and the turbine 187.

Referring now to Figures 31 and 32 of the drawings, there is shown a device 200 according to a sixth embodiment. The device 200 is somewhat similar to the apparatus 180 in the previous embodiment in the sense that there are a plurality of pumping chambers 201 connected in series. In this embodiment, the pumping chambers 201 are defined by a flexible wall structure 203 carried on a rigid support structure 205. The pumping chambers 201 are separated one from another by partitions 207 within the flexible wall structure 203, with each partition

being provided with a port 209 and associated one-way valve (not shown) such that working fluid can flow from one pumping chamber 201 to the next pumping chamber with progressively increasing pressure. The direction of flow is depicted by the arrows appearing in the flow circuit 211. The flow circuit 211 incorporates a turbine 213 as was the case in the previous embodiment.

In this embodiment, the flexible wall structure 203 deflects in response to wave action to provide the pumping action. The circuit 211 may incorporate hinged joints 215 to accommodate movement between the flexible wall structure 203 and the associated rigid support structure 205 with respect to the turbine 213.

Referring now to Figures 33 and 34, there is shown a device 220 according to a seventh embodiment. The device 220 is somewhat similar to the previous embodiment in the sense that there are a series of pumping chambers 221 defined within a flexible wall structure 223 supported on a rigid structure 225. The interior of the flexible wall structure 223 is partitioned to provide the series of pumping chambers 221, with each pumping chamber 221 communicating with the next pumping chamber via a one-way valve. The apparatus 220 also incorporates a flow circuit 227 in which there is provided a turbine 229. The device 220 differs from the device 200 of the previous embodiment in that there is provided a high pressure reservoir 231 upstream of the turbine 229 in the flow circuit 227 and a low pressure reservoir 233 downstream of the turbine 229. With this arrangement, working fluid can accumulate under pressure in the high-pressure reservoir 231 until such time as it attains a predetermined pressure at which it can flow through the turbine 229 and into the low-pressure reservoir 233. In this embodiment, the turbine 229 and the two reservoirs 231, 233 are assembled and installed as a single unit 235. As was the case with the previous embodiment, hinges 237 are incorporated between sections 239 of pipe work providing the flow circuit 227 to accommodate movement between the flexible wall structure 223 and the associated rigid support structure 225 relative to the unit 235 which provides the turbine 229 and the two reservoirs 231, 233.

A wave power generation apparatus according to the invention provides a simple yet highly effective arrangement for harnessing energy available from wave

motion. The total available energy from wave motion is estimated at 2 billion kW worldwide. Harnessing just 0.1% of this available energy would satisfy the world electricity need more than 5 times over. In Australia only, it is estimated that some 1 million GWh of wave energy is dissipated on the southern shores each year.

Waves in deep water do not touch the bottom, and it is only when the depth of water is typically about one-half the wave length that wave energy is felt at the bottom. Accordingly, the relationship between depth and wave length affects the potential wave energy distribution. Therefore, placement of the apparatus in shallow water on the seabed is likely to provide optimum conditions for operation. Shallow water operation is also beneficial in terms of power transmission from the apparatus to the nearby mainland.

Energy extraction devices according to the various endorsements are each conducive to the installation in a submerged condition in shallow waters. The feature of submerged installation is also advantageous in the sense that its presence is not visually apparent and is therefore not unsightly.

The devices may also provide the benefit of acting as a wave destroyer or an artificial reef in that most of the wave energy is dissipated in operation of the apparatus, with the desirable result that calmer waters exist on the side of the apparatus opposite to the oncoming waves. Typically, the calmer waters are on the landward side of the reef and usually adjacent to the shoreline.

The devices have little impact on the environment, apart from the positive impact of calming the waters on the side thereof opposite oncoming waves. The calmer waters may provide a benefit of promoting marine life.

It should be appreciated that the scope of the invention is not limited to the scope of the various embodiments described.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to

imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

The Claims Defining the Invention are as Follows

1. A method of extracting useful energy from wave motion in a body of water, comprising: providing an energy extraction device having an energy collection surface responsive to variations in hydrostatic pressure generated by wave motion; positioning the energy extraction device in the body of water at a location where the body of water is at a depth D and a wave length λ, wherein the ratio of water depth to wave length (D/λ) is in a range of about 0.1 to 0.5; and extracting useful energy delivered by the energy extraction device.

2. A method according to claim 1 further comprising providing the energy extraction device with a rigid surface in opposing relation to the oncoming wave distribution in the body of water.

3. A method according to claim 2 wherein the energy collection surface has an extent in the direction of wave motion and the rigid surface extends downwardly from adjacent the energy collection surface.

4. A system for deriving useful work from wave motion, the system comprising a body of water subject to wave motion on the surface thereof, an energy extraction device submerged in the body of water, the energy extraction device having an energy collection surface responsive to variations of hydrostatic pressure arising from the wave motion, the energy extraction device being submerged in the body of water at a location where the water is of a depth D and of a wave length λ, with the ratio of water depth to wave length (D/λ) being in the range of about 0.1 to 0.5.

5. A system for deriving useful work from wave motion, the system comprising a body of water subject to wave motion on the surface thereof, an energy extraction device submerged in the body of water, the energy extraction device comprising an energy collection surface responsive to variations of hydrostatic pressure arising from wave motion above the energy collection surface, and a rigid surface extending downwardly from the energy collection

surface for intercepting water disturbances generated by the wave motion and deflecting the water disturbances to the region above the energy collection surface.

6. A system according to claim 5 wherein the energy collection surface has an extent in the direction of wave motion and the rigid surface extends downwardly from adjacent the energy collection surface.

7. An energy extraction device for extracting energy from wave motion in a body of water, the energy extraction device comprising a body having an energy collection surface responsive to variations in hydrostatic pressure arising from wave motion above the energy collection surface, and a rigid surface extending downwardly from the energy collection surface for intercepting water disturbances generated by the wave motion and deflecting the water disturbances to the region above the energy collection surface.

8. An energy extraction device according to claim 7 wherein the body has an upper surface in which the energy collection surface is incorporated.

9. An energy extraction device according to claim 8 wherein the upper surface of the body has a rigid section adjacent to the energy collection surface, the rigid section being disposed to the side of the energy collection surface opposite to the oncoming wave disturbances.

10. An energy extraction device according to claim 9 wherein the energy collection surface comprises a deflectable diaphragm.

11. An energy extraction device according to claim 10 wherein the diaphragm comprises a flexible diaphragm .

12. An energy extraction device according to any one of claims 7 to 11 wherein the body defines a pumping chamber containing a working fluid, a wall of the pumping chamber being defined by a diaphragm whereby deflection of the

diaphragm in response to wave motion acts on working fluid contained in the pumping chamber to cause motion thereof.

13. An energy extraction device according to claim 12 wherein the working fluid comprises a gas or gaseous mixture such as air.

14. An energy extraction device according to any one of claims 7 to 13 further comprising conversion means responsive to flow of the working fluid for converting kinetic energy in the moving working fluid to an energy form that can be delivered as useful work.

15. An energy extraction device according to claim 14 wherein the conversion means comprises a fluid motor for converting the motion of the working fluid to rotary motion from which mechanical power can be extracted as shaft power.

16. An energy extraction device according to claim 15 wherein the fluid motor comprises a turbine.

17. An energy extraction device according to any one of claims 11 to 16 wherein the body incorporates two zones and a flow path between the two zones along which the fluid can move between the two zones, the fluid motor being associated with the flow path.

18. An energy extraction device according to claim 16 or 17 wherein the turbine is accommodated in a nozzle structure.

19. An energy extraction device according to claim 18 wherein the nozzle structure is accommodated in the flow path.

20. An energy extraction device according to any one of claims 15 to 19 wherein the fluid motor has an axis of rotation disposed substantially horizontally.

21. An energy extraction device according to any one of claims 10 to 20 wherein the diaphragm has an extent in the direction of wave motion of a dimension of

no more than one half of the wavelength of wave activity to which the device would be exposed in normal circumstances.

22. An energy extraction device according to any one of claims 11 to 16 wherein the working fluid moves through a circuit incorporating the pumping chamber and the fluid motor .

23. An energy extraction device according to claim 22 wherein a circuit further comprises one-way valves for controlling the flow direction therealong.

24. An energy extraction device according to claim 22 or 23 wherein the circuit further comprises an accumulator chamber and a transitional chamber, the arrangement being that the working fluid is delivered from the pumping chamber into the accumulator chamber upon inward deflection of the diaphragm to preform discharge stroke of the pumping chamber, the working fluid accumulating in the accumulator chamber until it attains a prescribed pressure whereupon it flows through the fluid motor and into the transitional chamber, the working fluid returning from the transitional chamber to the pumping chamber upon outward deflection of the diaphragm to perform an intake stroke of the pumping chamber.

25. An energy extraction device according to claim 22 or 23 wherein the circuit comprises a further chamber, the pumping chamber and the further chamber being connected for fluid communication therebetween by means of a delivery path and a return path, the fluid motor being associated with the delivery path, the arrangement being that working fluid is delivered from the pumping chamber to the further chamber to flow through the fluid motor upon inward deflection of the diaphragm to perform a discharge stroke of the pumping chamber, and working fluid returning from the further chamber to the pumping chamber upon outward deflection of the diaphragm to perform an intake stroke of the pumping chamber.

26. An energy extraction device according to claim 25 wherein the further chamber is of constant volume in the sense that it is not affected by variations in hydrostatic pressure arising from the work motion.

27. An energy extraction device according to claim 17, 18 or 19 wherein one zone defines the pumping chamber and the other zone defines a further pumping chamber, the two pumping chambers being adapted to operate in opposition.

28. An energy extraction device according to claim 27 wherein the diaphragms of the two pumping chambers are offset with respect to each other in the direction of wave motion.

29. An energy extraction device according to claim 28 wherein the two diaphragms have centres spaced substantially equal to one-half of the length of the predominant wave disturbances to which they are exposed.

30. An energy extraction device according to any one of claims 10 to 29 wherein the body has a peripheral wall which is generally circular in plan.

31. An energy extraction device according to any one of claims 10 to 29 wherein the body has a peripheral wall which is substantially rectangular in plan.

32. A method of extracting useful energy from wave motion in a body of water, the method being substantially as herein described.

33. A system for deriving useful work from wave motion substantially as herein described with reference to the accompanying drawings.

34. An energy extraction device substantially as herein described with reference to the accompanying drawings.

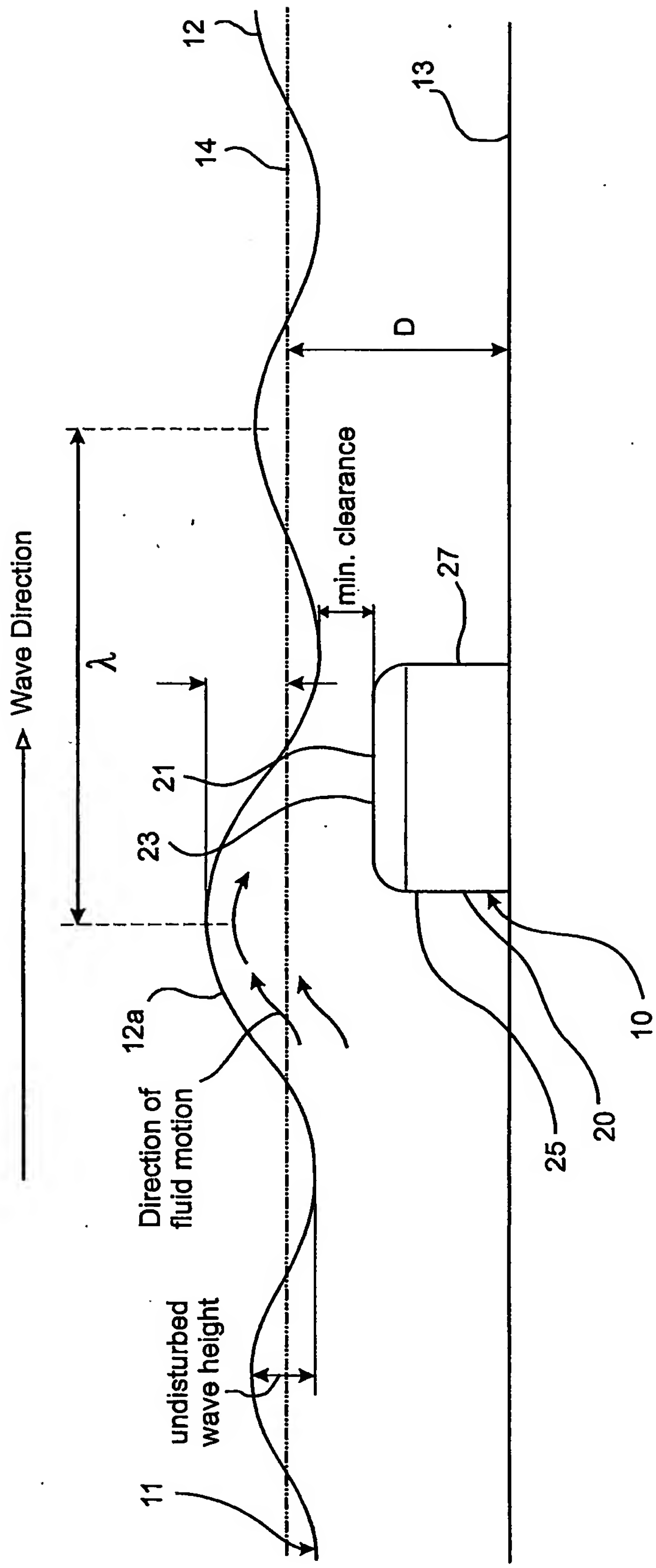
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Fig 1

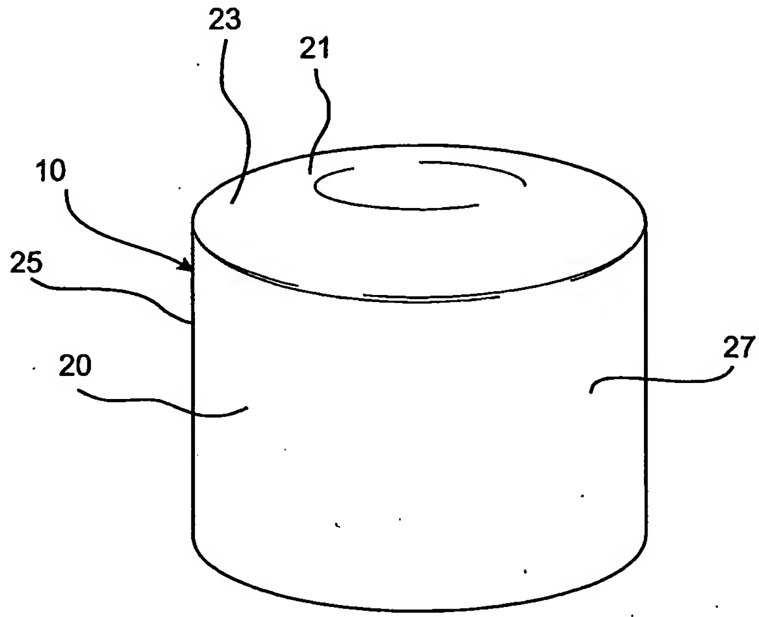

Fig 2

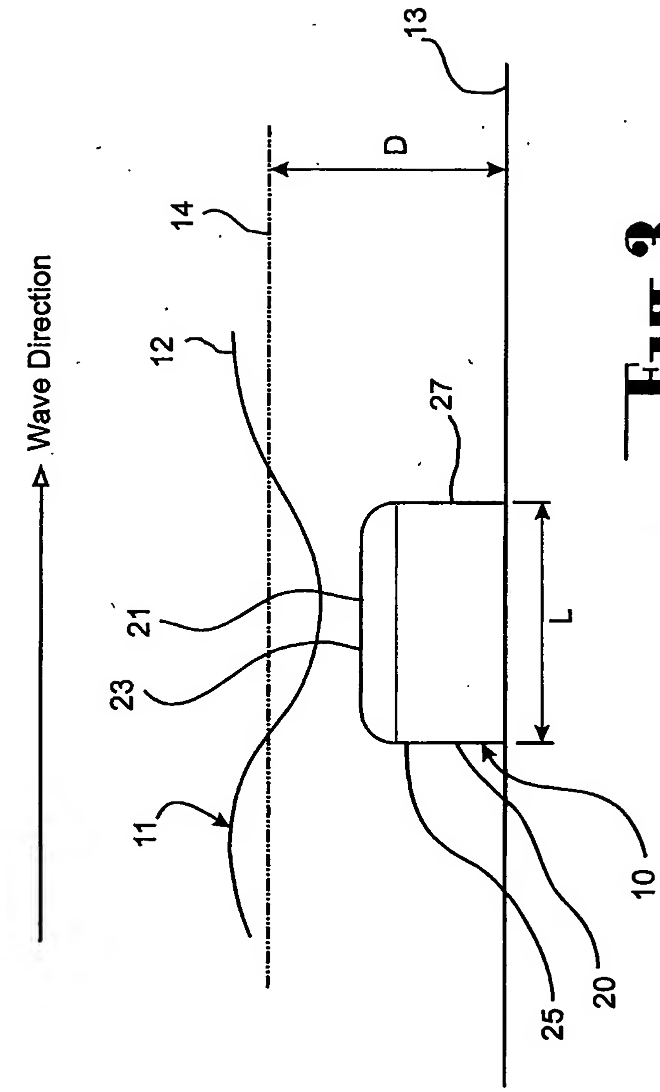

Fig. 3

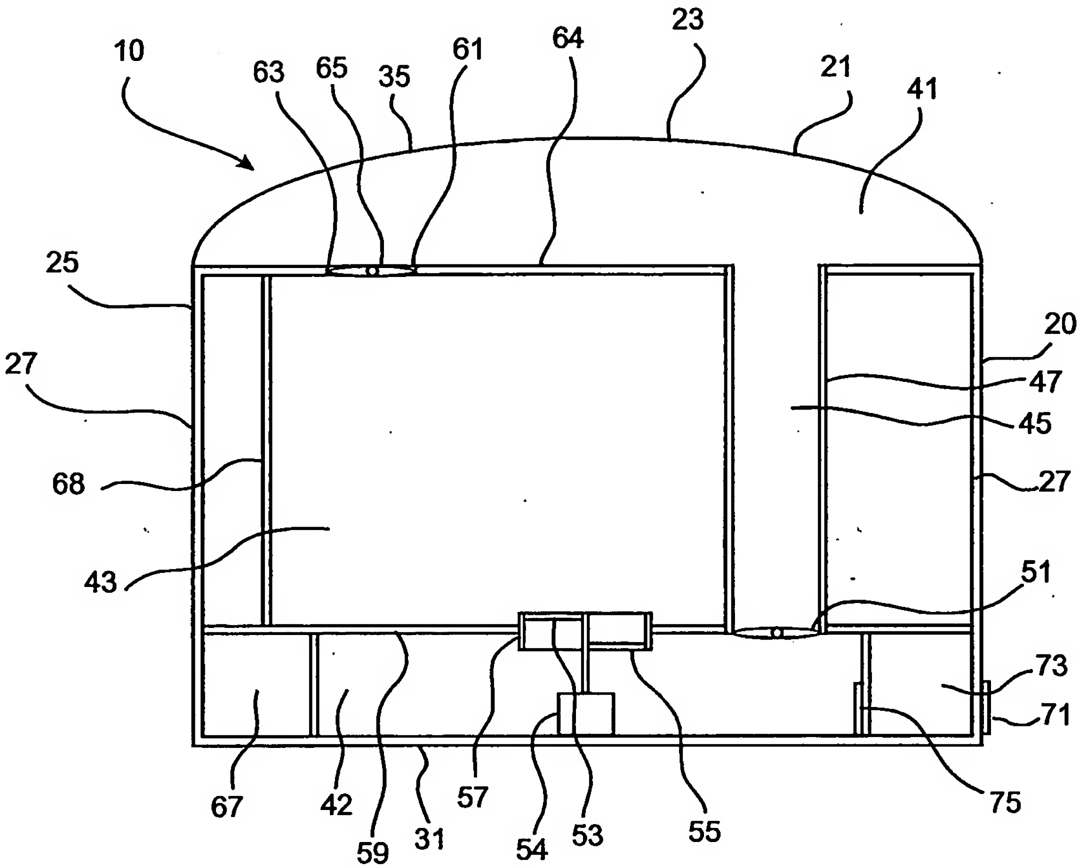
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Fig.4

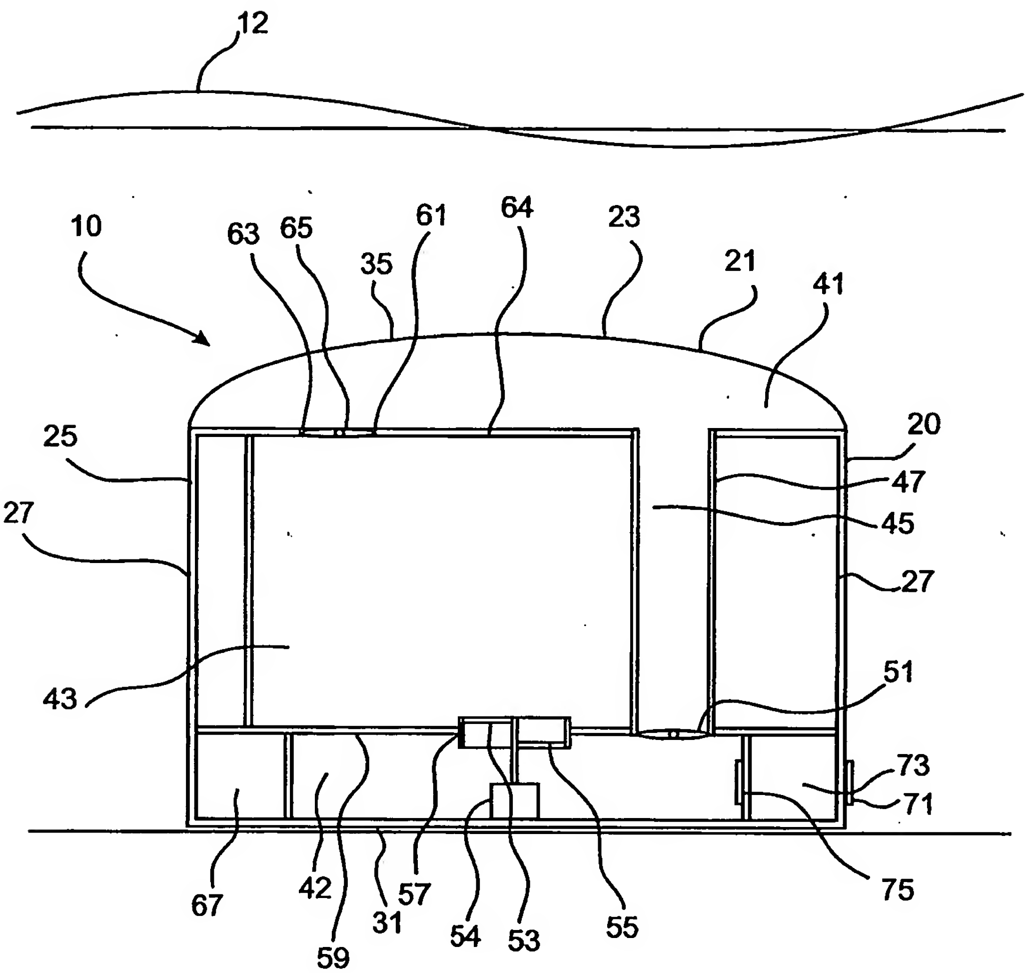
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Fig.5.

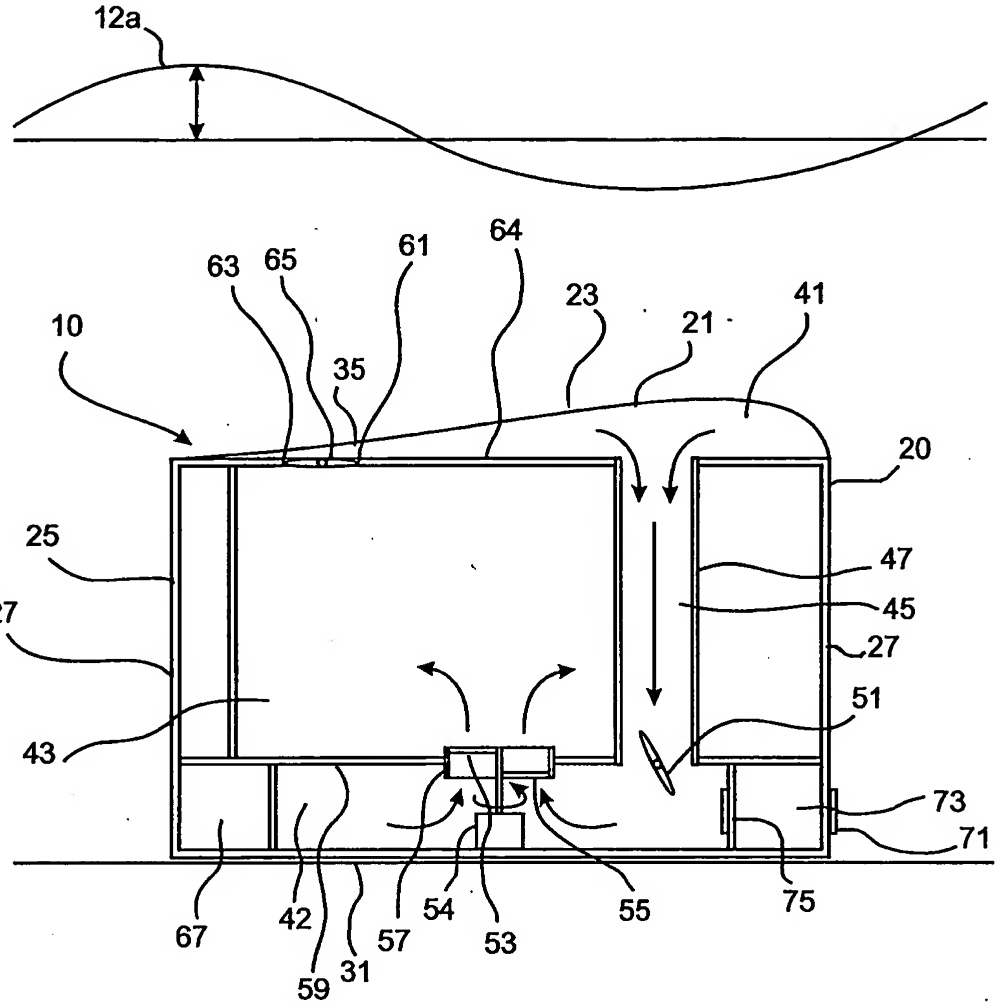
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Fig.6.

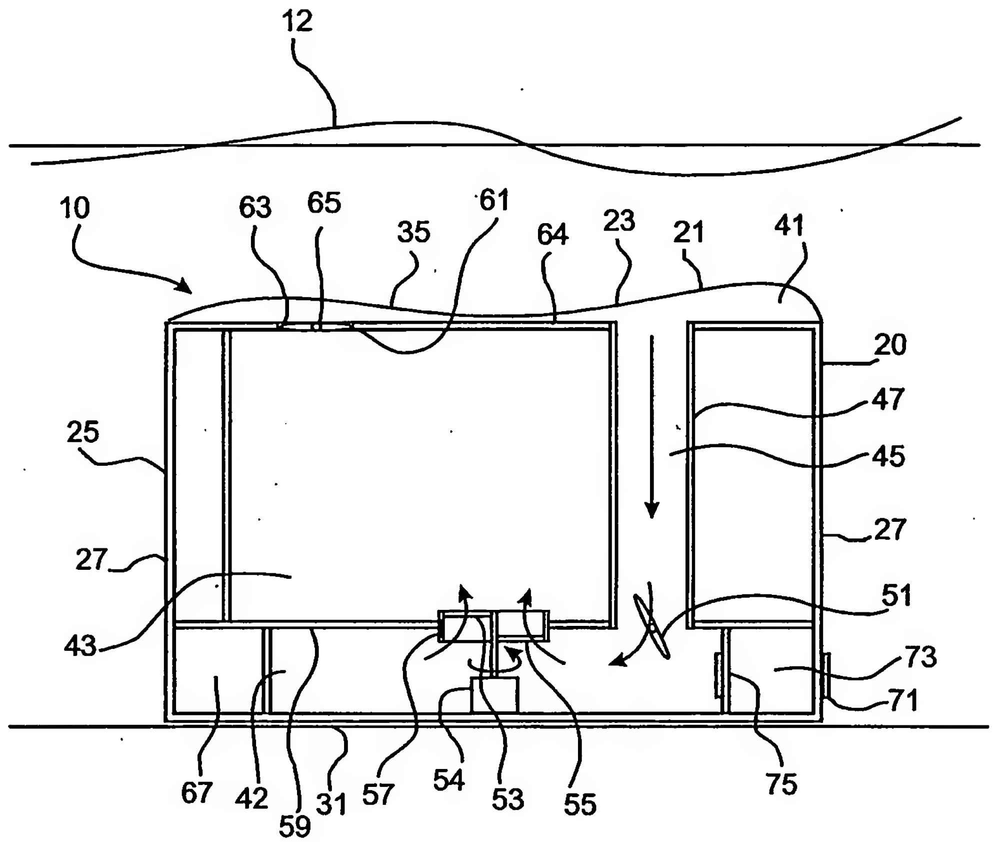
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Fig.7.

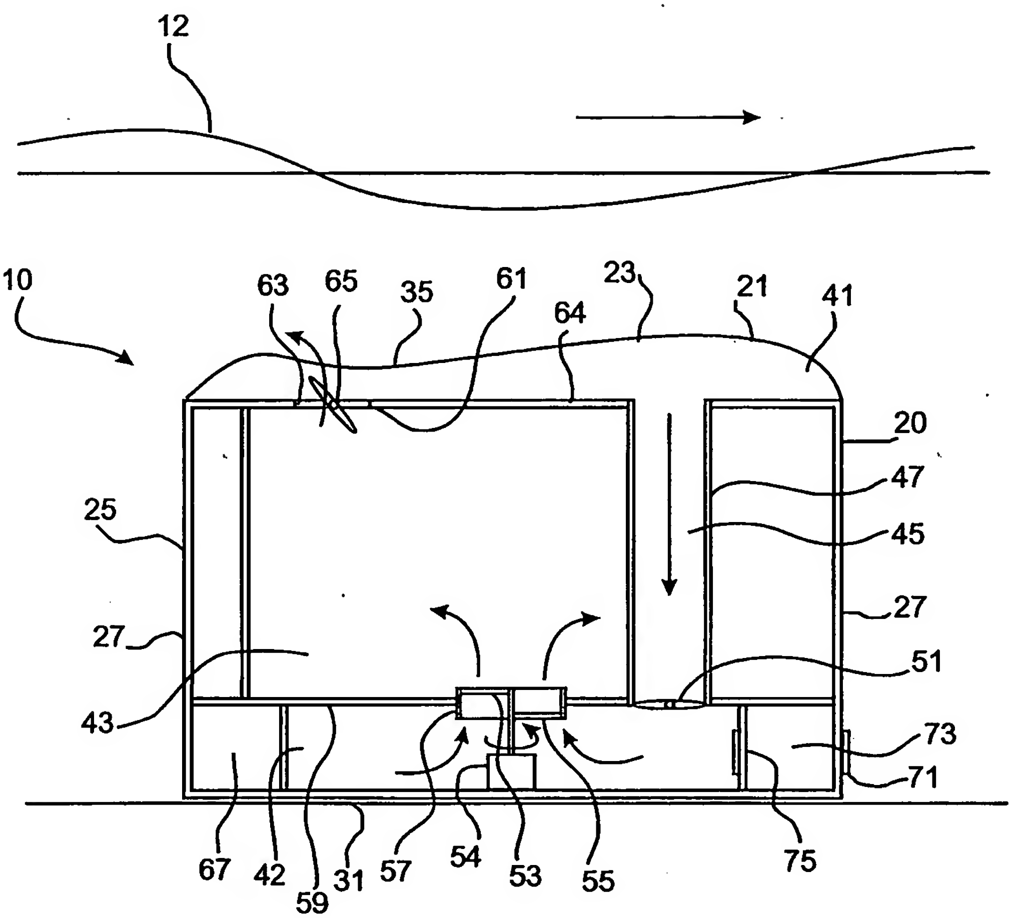
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Fig. 8.

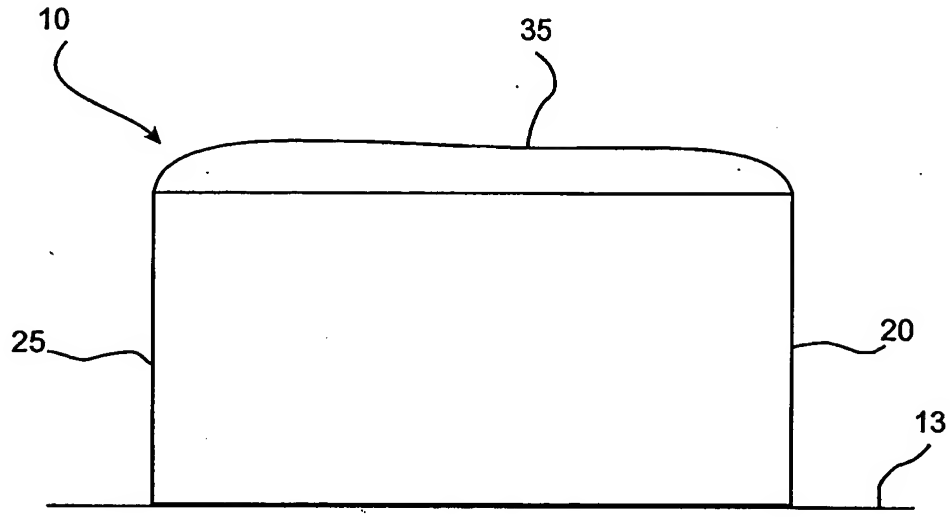

Fig. 9

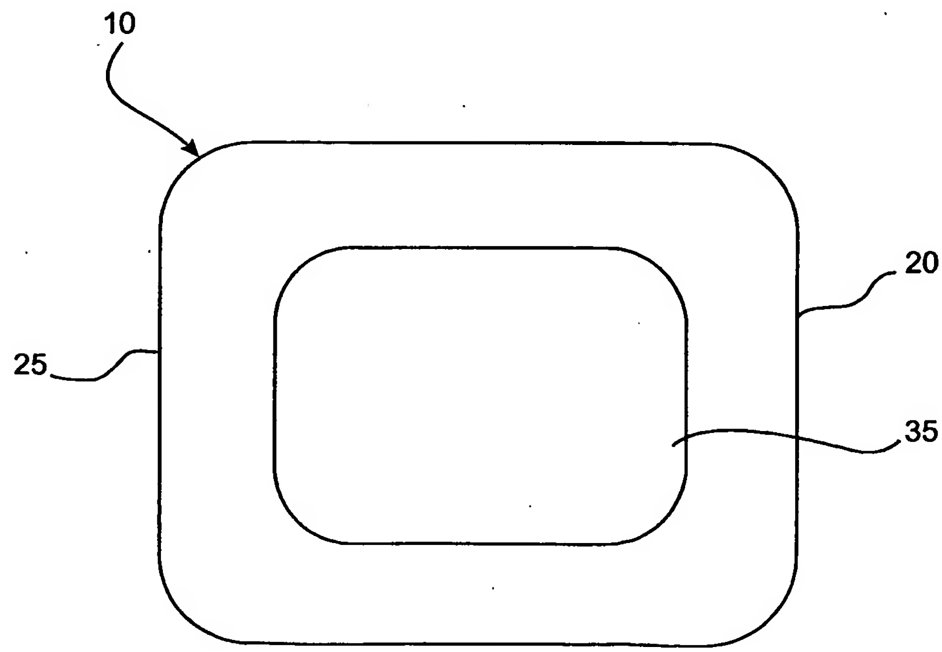

Fig. 10

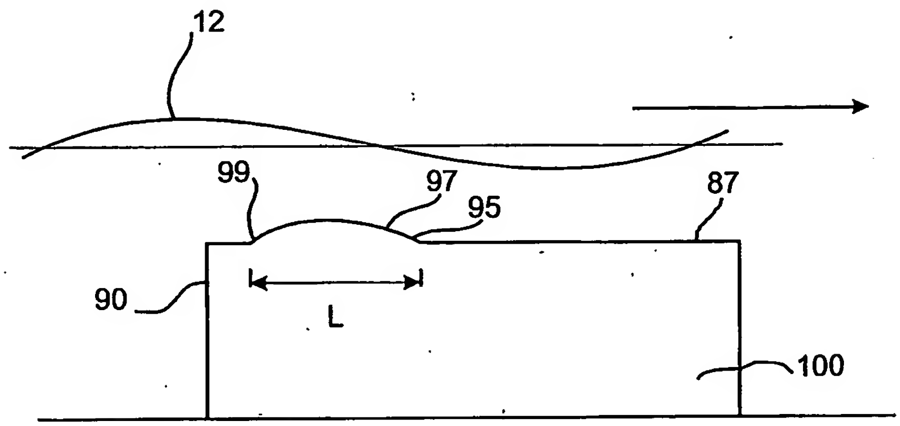

Fig.11.

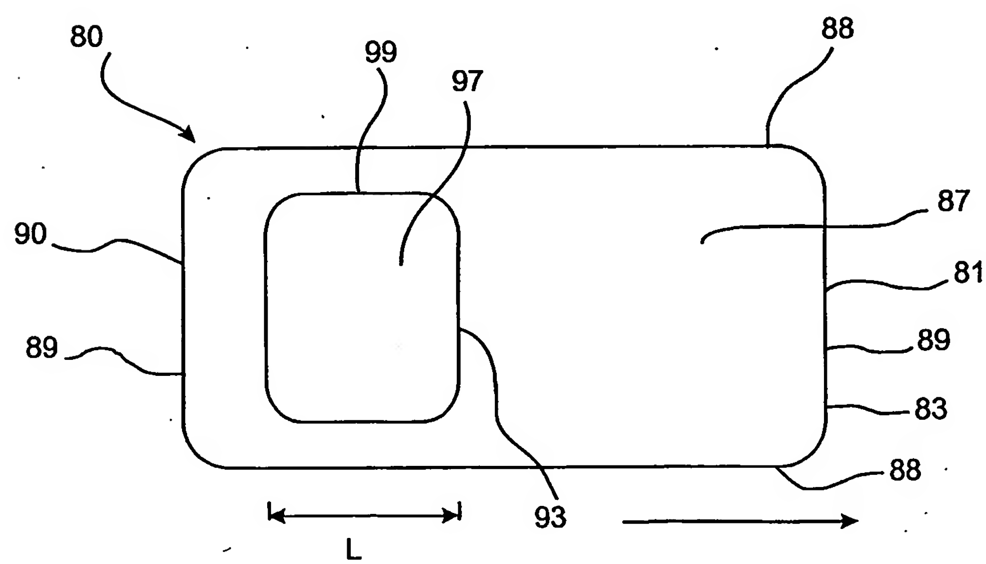

Fig.12.

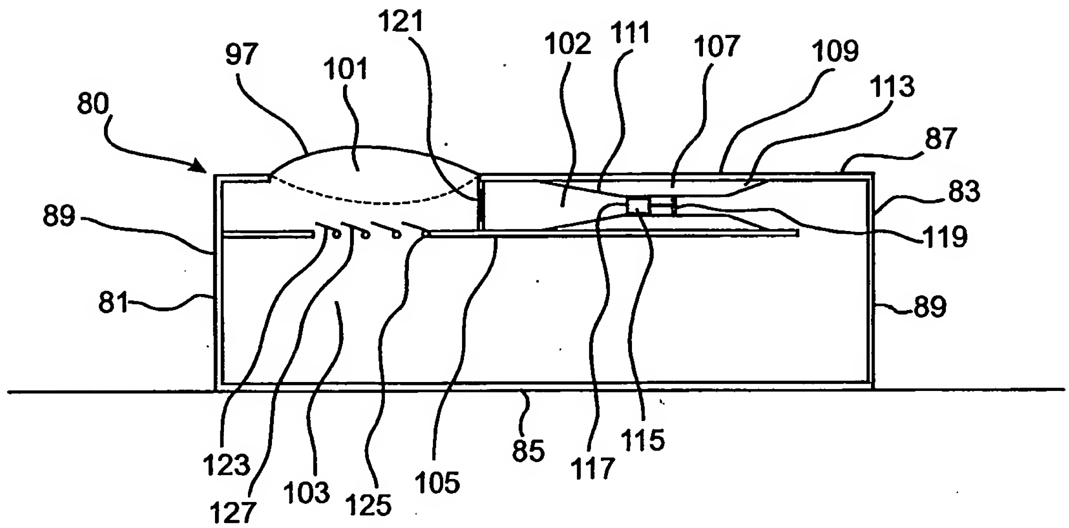
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Fig 13

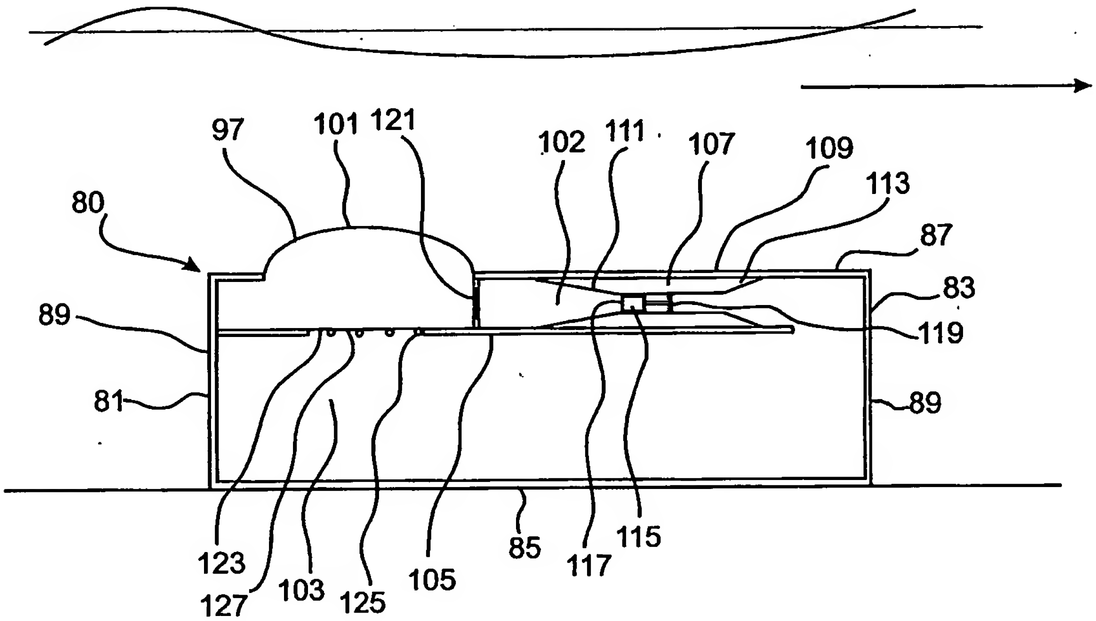
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Fig.14.

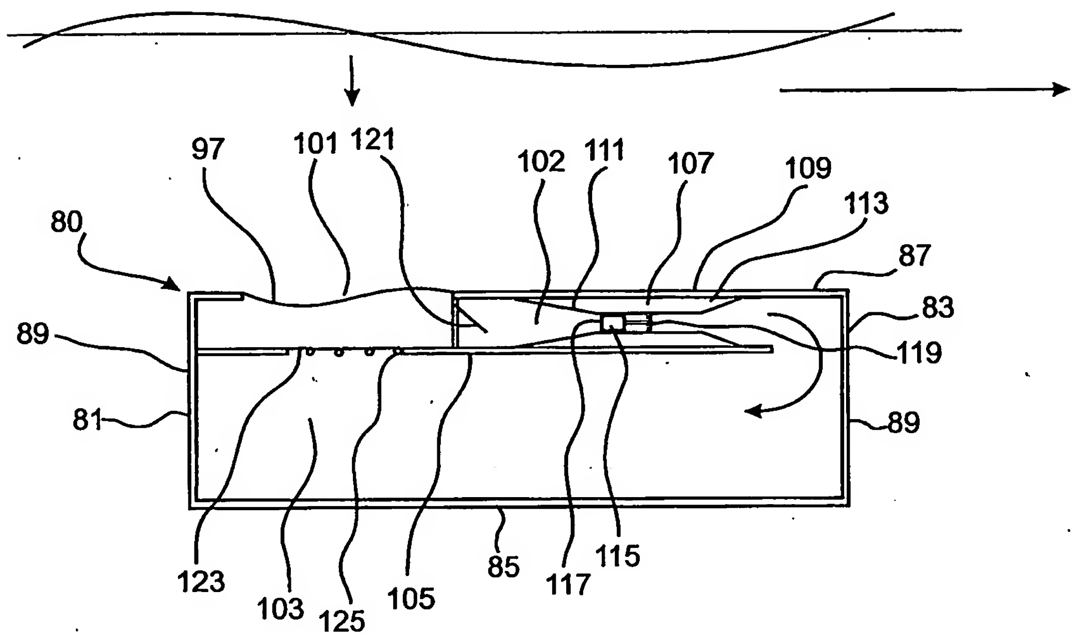
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Fig. 15.

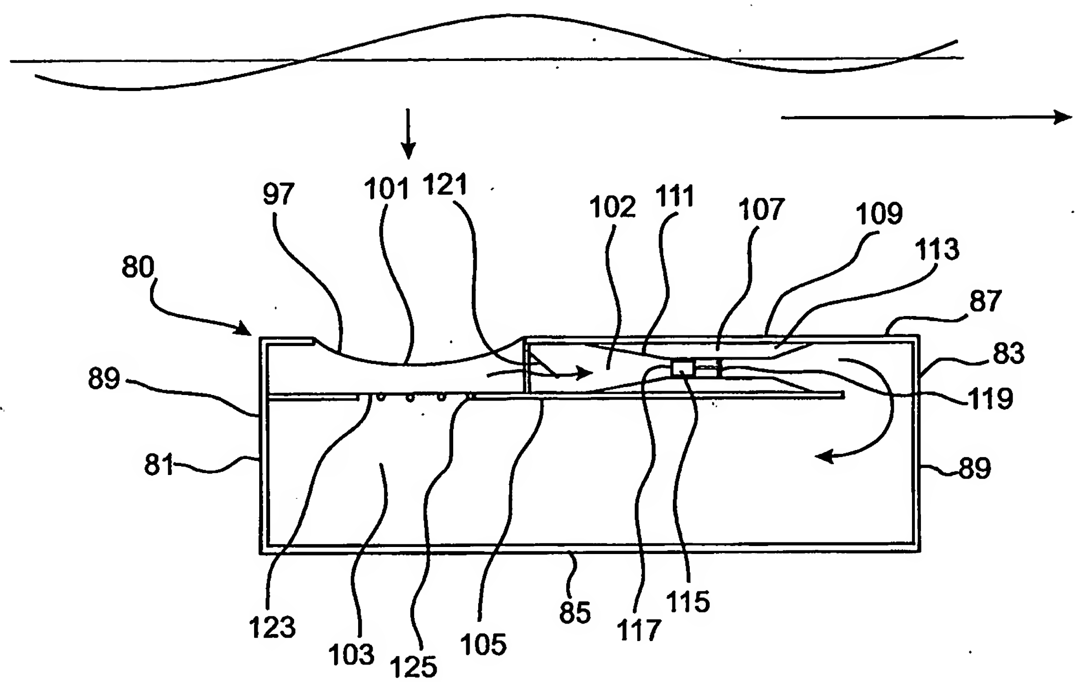
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Fig.16.

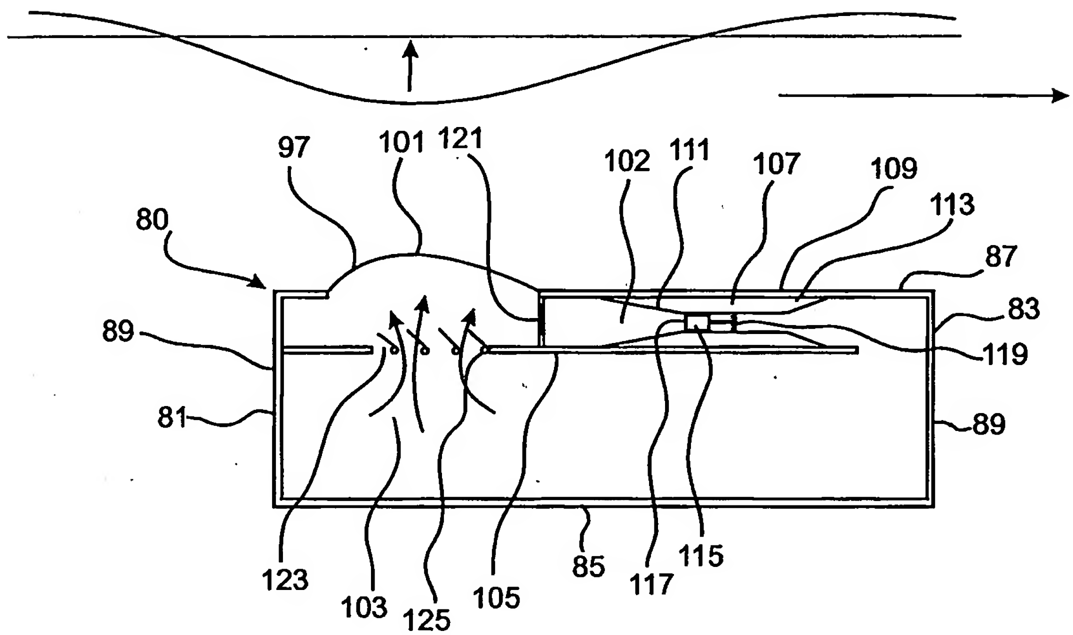
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Fig.17.

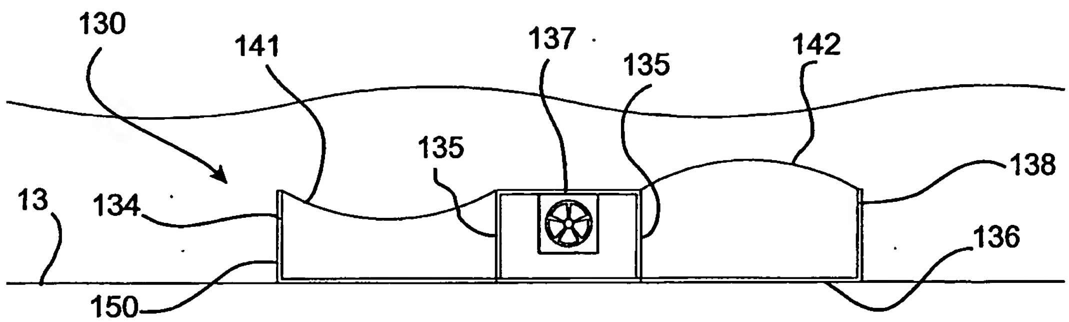
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Fig. 18

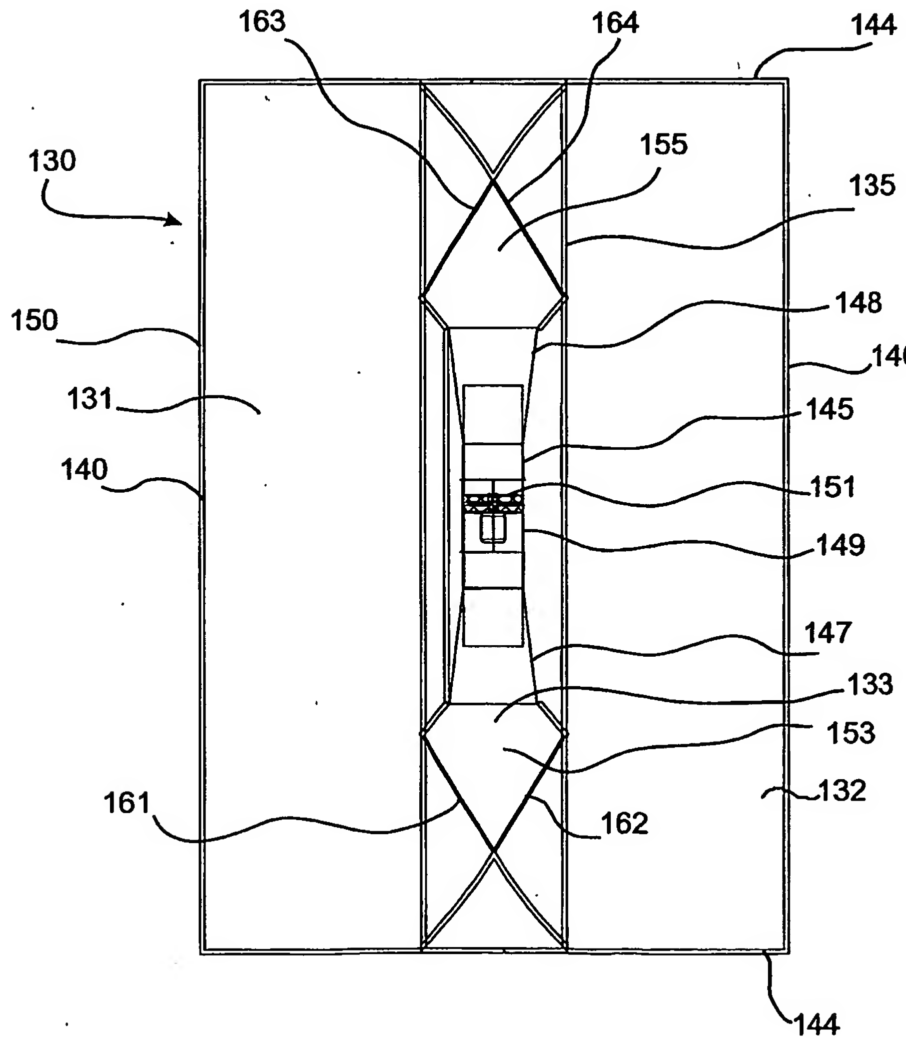
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Fig. 19

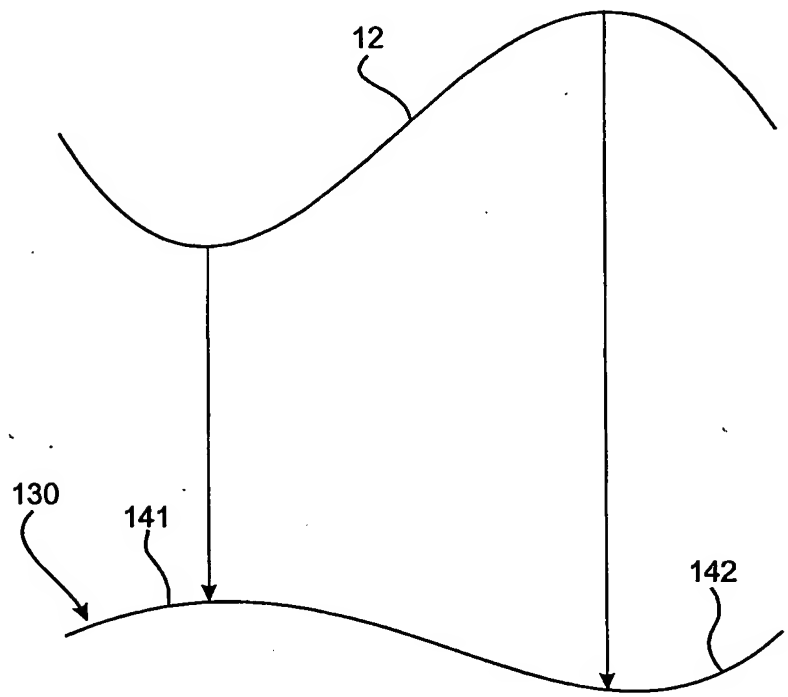

Fig. 20

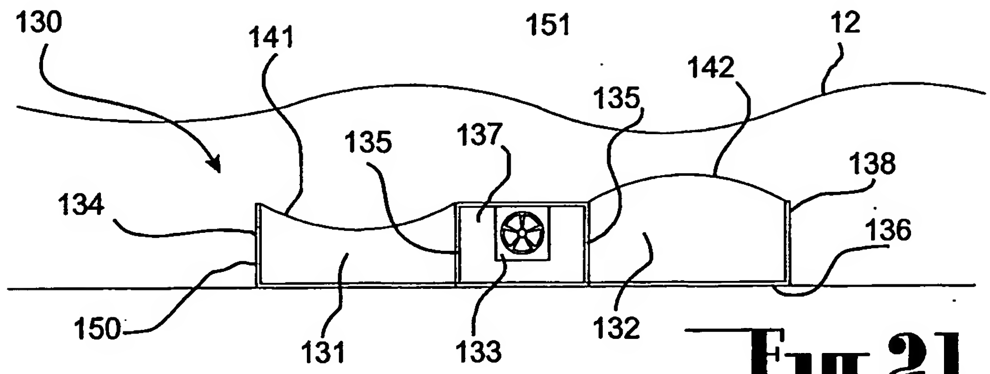
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Fig.21

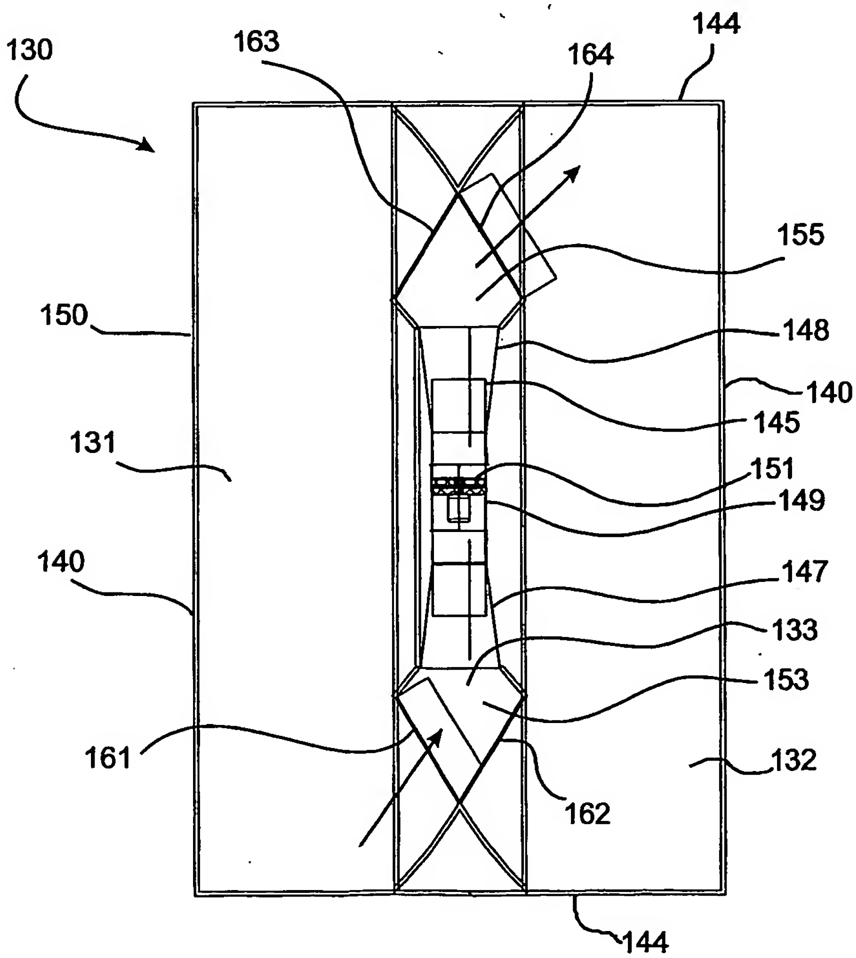
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Fig.22

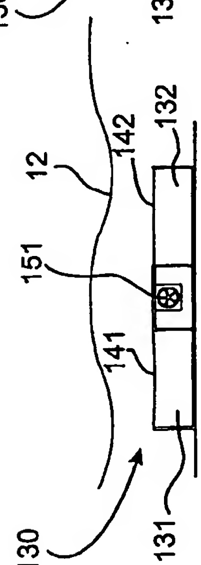

Fig 23

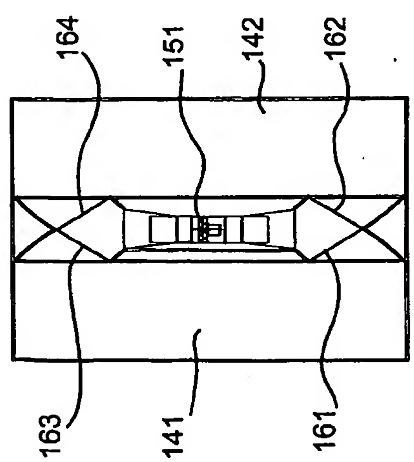

Fig 24

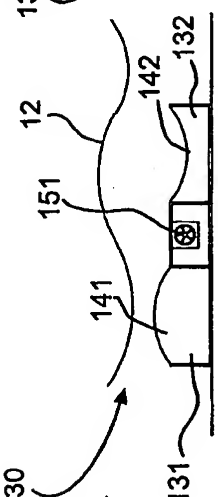

Fig 25

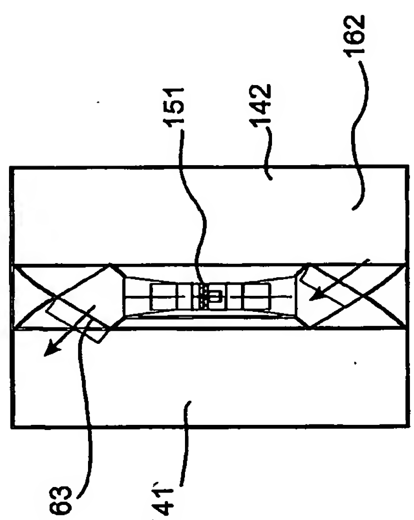

Fig 26

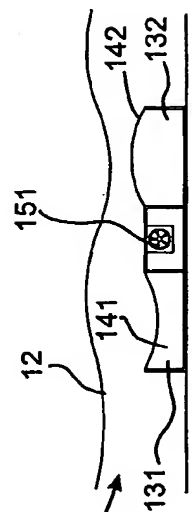

Fig 27

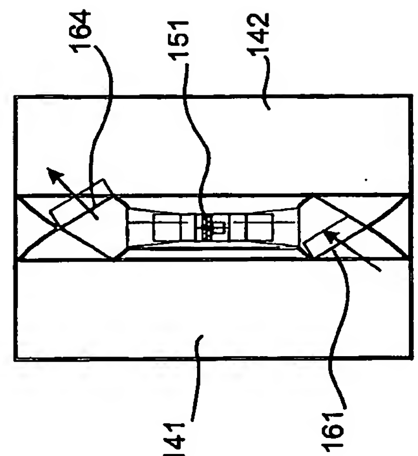

Fig 28

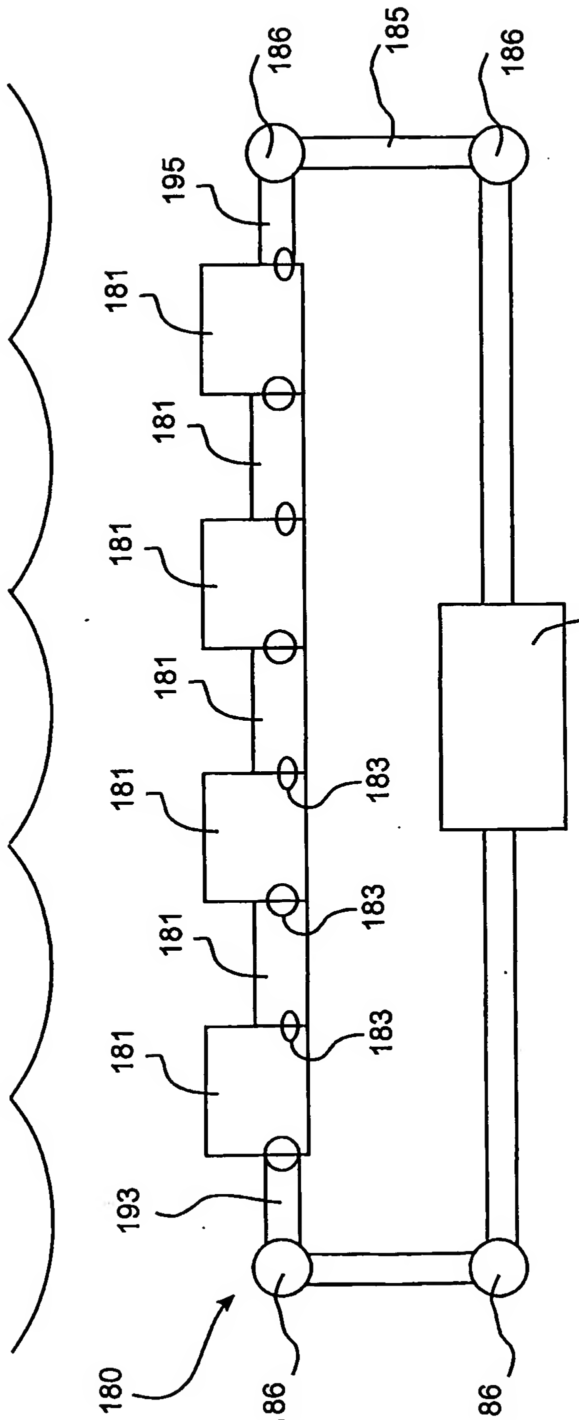
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Fig 29

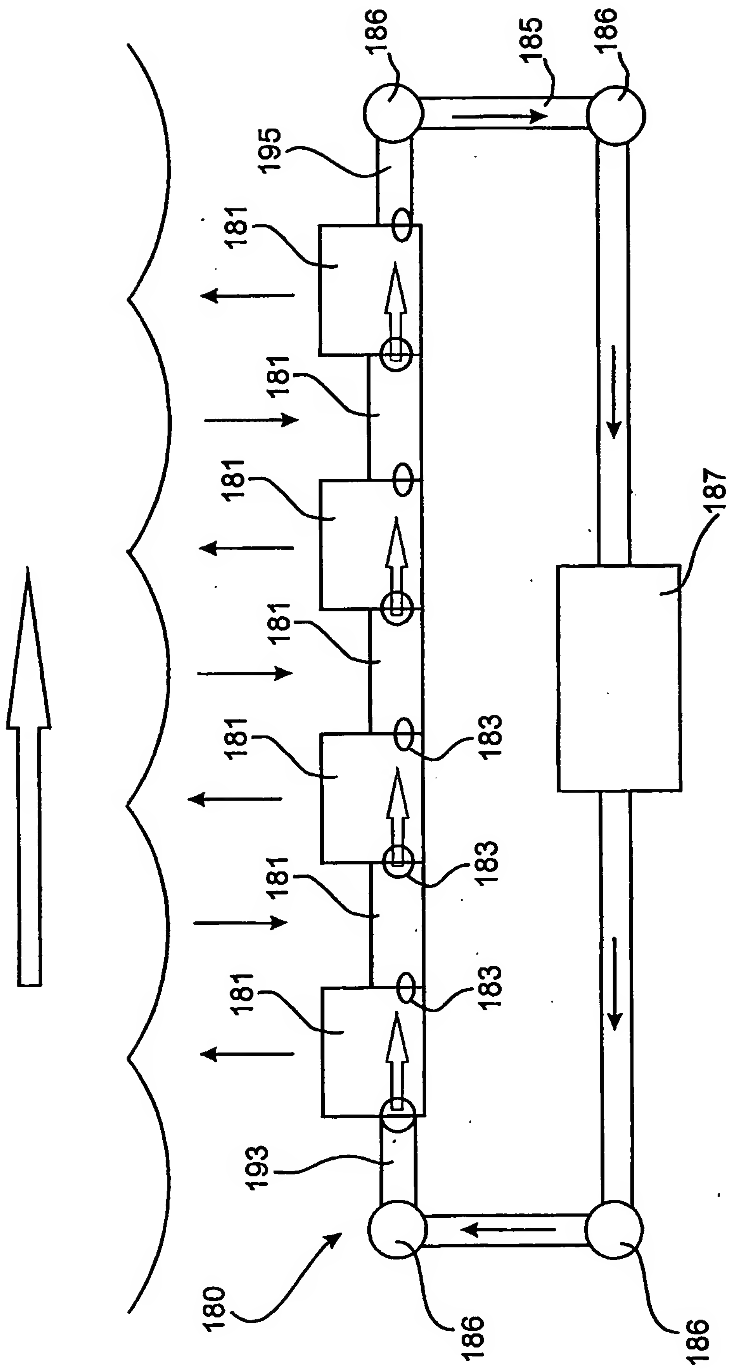
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Fig 30

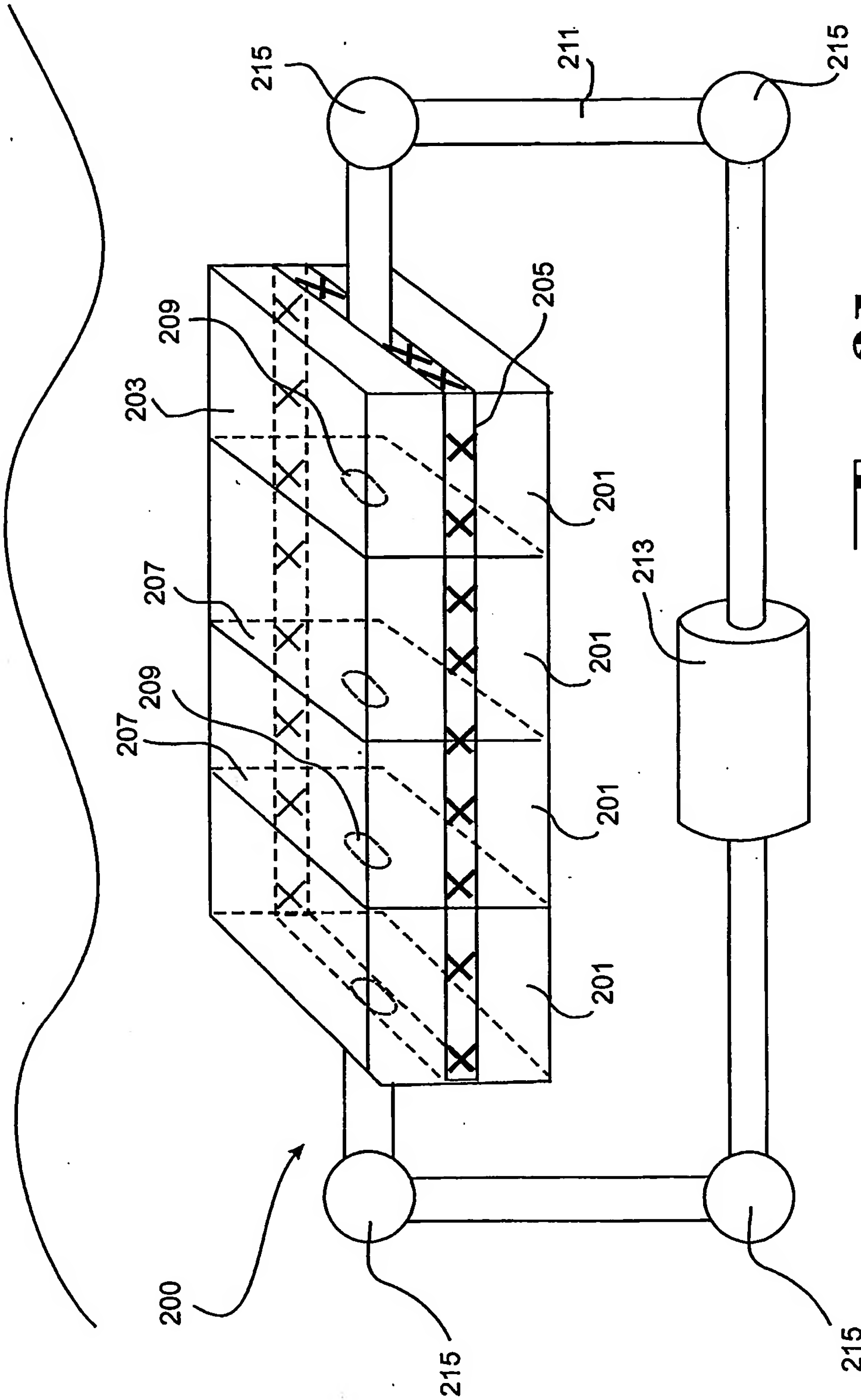
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Fig 31

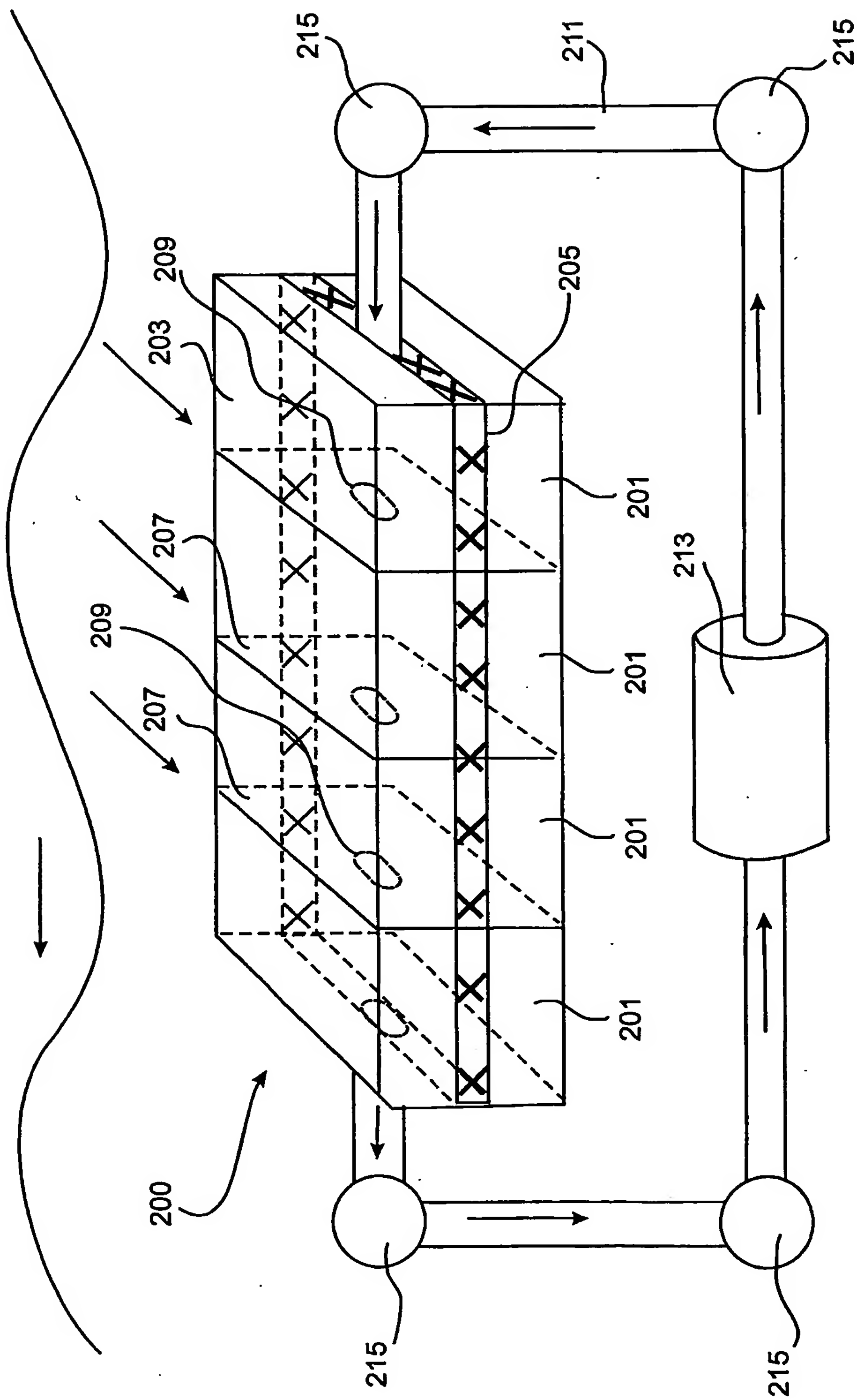
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Fig 32

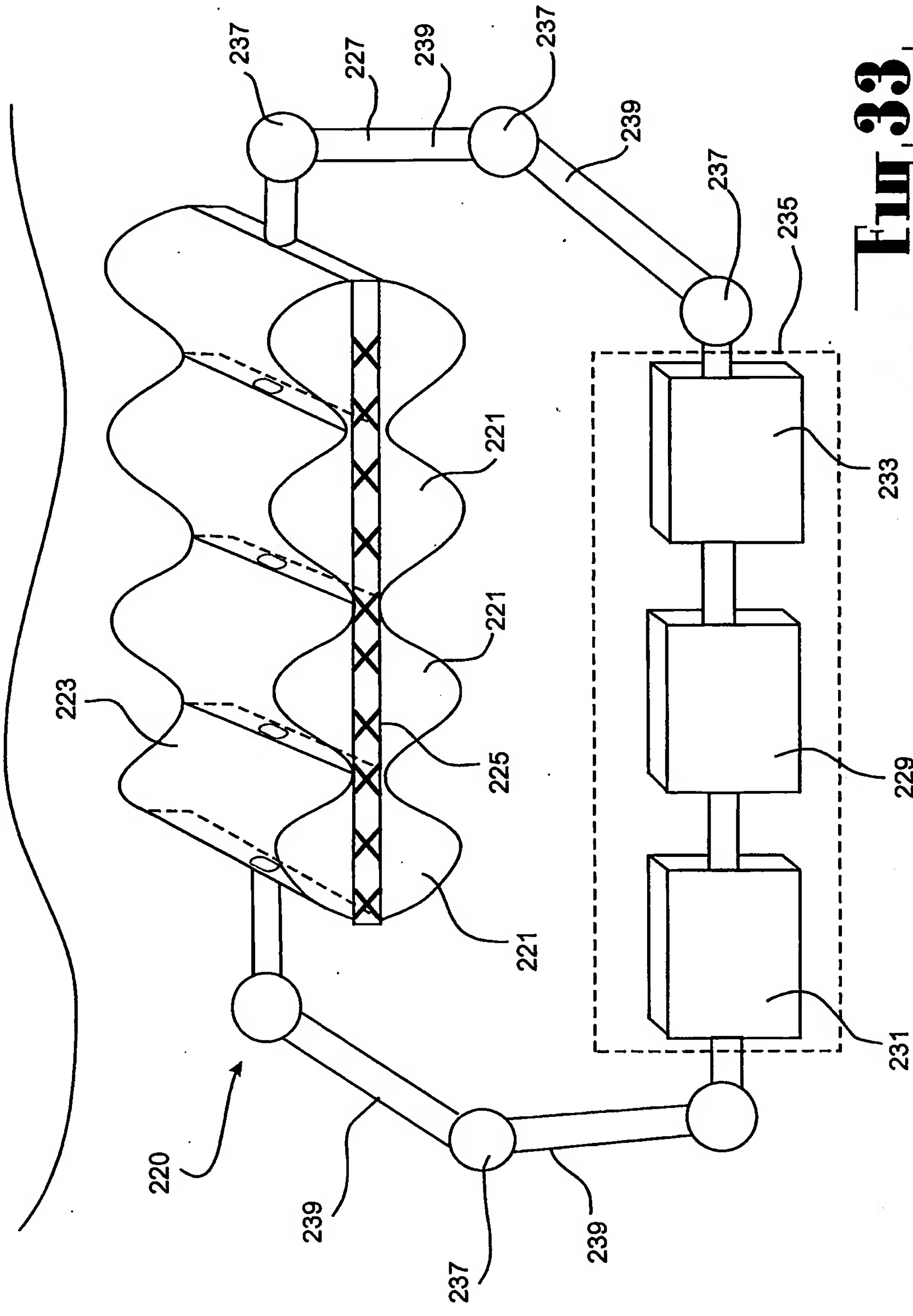
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Fig 33

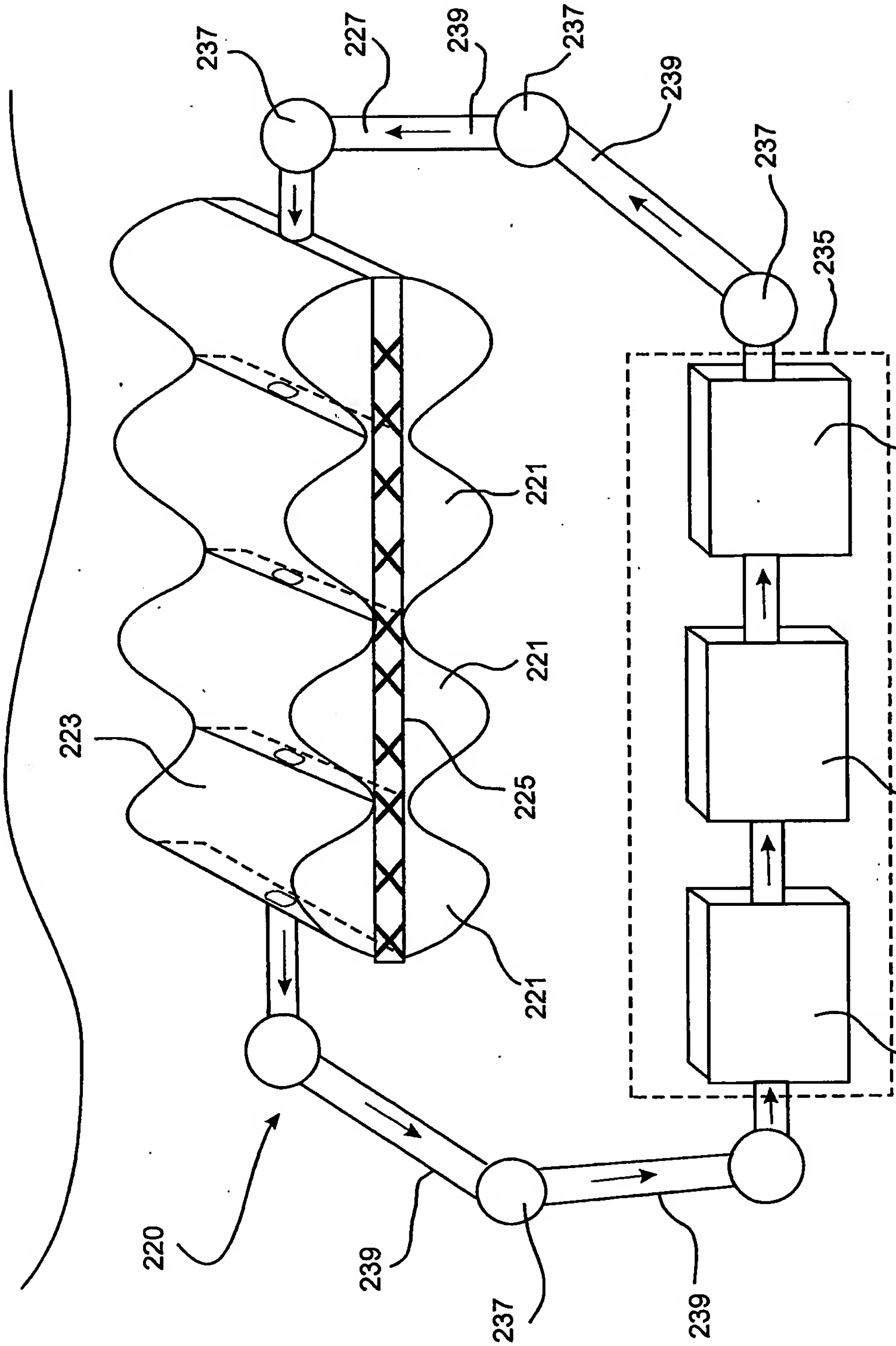
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Fig. 34

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01425

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: E02B 9/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (7) : E02B 9/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC E02B 9/08

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Derwent Patents File : Dwpi

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NL 7407807 A (GUSTAFSON) 20 December 1974. Derwent english language abstract, accession no. A0705W, Class Q55.	1,4,5,7
A	DE 19504356 A (BOLTZ) 14 August 1996. All document.	1,4,5,7
A	DE 2648318 A (GOPPNER) 27 April 1978. All document.	1,4,5,7
A	DE 2750616 A (The QUEEN'S UNIVERSITY of BELFAST) 24 May 1978.	1,4,5,7
A	DE 19734077 A (RANZ) 15 October 1998. All document.	1,4,5,7
A	FR 2548738 A (LIAUTAUD) 11 January 1985. All document.	1,4,5,7

[X] Further documents are listed in the continuation of Box C   [X] See patent family annex

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search
13 November 2002

Date of mailing of the international search report
18 NOV 2002

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01425

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95/17555 A (TEAMWORK TECHNIEK BV) 29 June 1995. All document.	1,4,5,7
A	WO 99/11926 A (A.W.S.BV) 11 March 1999. All document.	1,4,5,7

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU02/01425

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
NL	7407807/74	AU	70146/74	CH	567155	DE	2429057
		FR	2233507	GB	1452359	IN	141802
		JP	50026924	NO	742083	SE	7308523
		US	3965364	CA	1004836	DE	2330243
		FR	2189490	GB	1399316	IT	991633
		JP	49058105	NL	7308414	US	4163656
DE	19504356	NONE					
DE	2648318	FR	2369440				
DE	2750616	FR	2370875	GB	1595700	JP	53092060
		NL	7712434	SE	7712797	US	4221538
DE	19734077	NONE					
FR	2548738	NONE					
WO	9517555	AU	12041/95	BR	9408396	CA	2179641
		EP	736123	NL	9302230	US	5909060
		NZ	277120				
WO	9911926	AU	90079/98	BR	9812169	CA	2302389
		EP	1009933	NZ	503724	US	6256985
		ZA	9808059				

END OF ANNEX